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ELECTRONIC AND OPTICALLY GENERATED AIRCRAFT DISPLAYS: A STUDY OF STANDARDIZATION REQUIREMENTS

James M. Ketchel, et al

Matrix Corporation

May 1968

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13. ABSTRACT

This study reviewed and analyzed the research literature relating to electronically and optically generated aircraft displays. The purpose was to provide background information to support standardization of such displays for military aircraft. The scope of the inquiry was limited to vertical and horizontal situation displays, either of the direct view or projected (head-up) type, used by the pilot for aircraft and mission control. The results have been set forth under three major headings:

1) Information Requirements - a synthesis of 16 system studies and 11 current display designs to determine the basic information content necessary for general flight and certain special missions,

2) Symbology - an evaluation of research findings dealing with static and dynamic symbol characteristics and display format,

3) Display Characteristics - a delineation of optimum visual characteristics of displays in relation ot the conditions of use and the techniques of image generation.

The report also contains an extensive bibliography and specific recommendations for additional research.

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JOINT ARMY-NAVY AIRCRAFT INSTRUMENTATION RESEARCH

ELECTRONIC AND OPTICALLY GENERATED AIRCRAFT DISPLAYS

A STUDY OF STANDARDIZATION REQUIREMENTS

Prepared for JANAIR
Office of Naval Research
Contract N00014-67-C-0517
NR 231-060

THE MATRIX CORPORATION
JAMES M. KETCHEL
LARRY L. JENNEY

May 1968

435

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FOREWORD

This report presents work which was performed under the Joint Army Navy Aircraft Instrumentation Research (JANAIR) Program, a research and exploratory development program directed by the United States Navy, Office of Naval Research. Special guidance is provided to the program for the Army Electronics Command, the Naval Air Systems Command, and the Office of Naval Research through an organization known as the JANAIR Working Group. The Working Group is currently composed of representatives from the following offices:

U. S. Navy, Office of Naval Research, Aeronautics Programs, Code 461, Washington, D. C.

- Aircraft Instrumentation and Control Program Area

U. S. Navy, Naval Air Systems Command, Washington, D. C.

- Avionics Division; Navigation Instrumentation and Display Branch (NAVAIR 5337)
- Crew Systems Division; Cockpit/Cabin Requirements and Standards Branch (NAVAIR 5313)

U. S. Army, Army Electronics Command, Avionics Laboratory, Fort Monmouth, New Jersey

- Instrument Technical Area (AMSEL-VL-I)

The Joint Army Navy Aircraft Instrumentation Research Program objective is to conduct applied research using analytical and experimental investigations for identifying, defining, and validating advanced concepts which may be applied to future, improved Naval and Army aircraft instrumentation systems. This includes sensing elements, data processors, displays, controls, and man/machine interfaces for fixed and rotary wing aircraft for all flight regimes.

ASSP

The Aircrew Station Standardization Panel (ASSP) is a joint service working group responsible for the generation, coordination, and revision of military standards, specifications, and other regulatory documents dealing with the crew compartment of military aircraft and the equipment therein. The ASSP is composed of representatives of the U.S. Air Force, U.S. Army, U.S. Navy, and the Aeronautical Standards Group, with advisory participation by the U.S. Bureau of Standards and the National Aeronautics and Space Administration.

This report, while neither sponsored by the ASSP nor connected officially with its activities in any way, is an outgrowth of the efforts of the ASSP to establish a standard governing the design of electronic and optically generated displays for military aircraft.

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER I - INTRODUCTION

In its conception this study grew out of the participation by one of its authors in the efforts of an ASSP committee to establish a standard for electronic and optically generated displays. From the outset, the work of the committee has been hampered by uncertainty about what is the proper basis for such a standard. In a sense, electronic displays serve the same purpose as conventional aircraft instruments (or, more properly, combinations of them) and often resemble them in outward appearance. In fact, though, the similarity is largely superficial, and it is by no means certain that the large body of standards and regulatory documents pertaining to conventional instruments really have anything to do with the display of information by electronic media. On the other hand, electronic displays are not entirely new; CRTs have been used to display radar information for a quarter of a century. Radar display characteristics and symbology are extensively researched topics, and a wealth of literature on these matters is available. However, a question arises as to the extent to which the findings of research in radar displays can or should be applied to the design and standardization of electronic displays for flight.

This problem is by no means peculiar to the ASSP. It is merely a facet of the much larger problem facing the military services and the manufacturers of avionic equipment. That which prompted the ASSP to seek standardization has also been the concern of the JANAIR Program and its predecessor, ANIP, for over ten years. Simply put, it is this. With the advent of reliable airborne CRTs and other such devices, it has become possible to provide the pilot of military aircraft with a compact, integrated, multiparameter display of the flight situation. The versatility of this device permits almost any sort of presentation that might be desired. Its value to military aviation is indisputable. But immediately there arise questions about what information should be displayed, in what form, in what combinations and formats, and by what techniques. In short, how can we make best use of this new and flexible display medium?

Because the answers to these questions have been lacking, designers and military service users have been forced to proceed on the basis of best estimates and, at times, trial and error. As display designs have proliferated and new applications and techniques have been developed, the variety of symbology, information content, and display schemes has grown bewildering. Within this profusion there is both good and bad design, sense and nonsense, and a great deal of confusion. It seems reasonable that some sort of standardization is called for, not just to clear the air, but to satisfy certain basic needs of the military services and the industry which supports them. The most critical of these needs are:

1. The need to guarantee that the military services are getting the best equipment obtainable, not

just in terms of its airworthiness, but also in terms of its suitability to the missions of military aircraft.

2. The need to provide equipment which will enhance, and not hinder, pilot performance and promote safety of flight.

3. The need to minimize training requirements and, as a corollary, retraining requirements as old displays are supplanted by newer ones.

4. The need for the military services to have a yardstick by which to evaluate competing designs.

5. The need to provide guidance to designers in developing airborne display systems.

The overall purpose of this study, therefore, is to examine the available research literature to find information pertaining to electronic and optically generated displays. More specifically, the purpose is to identify those aspects of electronic flight displays which could now be standardized on the basis of existing information. In those areas where standardization seems desirable but where it is not now possible because of insufficient or inconclusive evidence, we have endeavored to indicate what further research is needed. As might be expected, the development of electronic and optically generated displays has been marked by certain controversies and differences of opinion, some of which still persist. Our purpose is not to revive old feuds. However, we have felt it necessary to reexamine some of these issues and to air various points of view in the interest of clarifying the problems involved and to make the point that these matters are seldom black and white and do not submit to simple solutions.

This report centers about three main topics.

1. Information requirements, where our interest is to define the basic information content of the display, both for general flight purposes and for certain special situations;

2. Symbology and format, in which our concern is to work toward a common display language, mode of presentation, and frame of reference;

3. Display characteristics, wherein our aim is to describe and quantify those features which arise from the electronic and optical techniques of display generation.

Our investigation is limited to those displays used by the pilot for the purpose of flight control, *i.e.*, displays of the horizontal and vertical situation of the aircraft. For the most part, we have dealt more extensively with displays for fixed wing aircraft than those for rotary wing or V/STOL aircraft. This imbalance was imposed upon us by the relative paucity of information about helicopter and V/STOL displays. In part, however, it is also a reflection of the current state of electronic display development, which has placed greatest emphasis on the fixed wing category.

Of necessity, we have had to restrict the range and depth of our investigation. Because of practical considerations of time and resources, we have not been able to pursue certain topics to the depth and detail that we would have liked. In other areas we suspect there is more information available, but we must confess to our inability to locate it or to obtain it in time for incorporation in this report. We do not pretend that our coverage of the topic is complete, not only for the above reasons, but also because we have worked under certain self-imposed limitations. Radar displays were purposely excluded by us because they are not central to our concern and because the topic has been covered by other investigators (e.g., Honigfeld, 1964). Airborne weapon control systems have hardly been touched upon because we did not feel we could do justice to such a complex topic in which the characteristics of the displays are largely determined by the nature of the individual weapon with which they are associated. Innovations and exotic display techniques, such as holograms, lasers, and X-rays, have likewise been by-passed since there is so little empirical research evidence now available on their application to airborne displays that commentary would be largely speculative.

This report is basically a summation of the results of a literature review. However, in the conduct of this study we were fortunate to be able to talk with some thirty or so persons who have long experience in the field of electronic displays and who are actively engaged in design or research. These conversations were of immeasurable value in stimulating our thinking and in guiding us to important research materials. The advice and comment of these persons has become so intermixed with our thinking that it has not always been possible to attribute them properly in the report itself. We would like to express our gratitude and ask them not to think unkindly of us for making full use of their counsel without always giving them specific recognition. We also take full responsibility for the interpretation of their ideas and apologize if we seem to have misconstrued their meaning.

We wish to emphasize that our intent has not been to write a standard for electronic and optically generated displays. Rather, we have endeavored to assemble and interpret the research data and other documentation upon which a standard could be based. The responsibility for developing the standard, if one is to be written at all, lies with the military services. Our aim has been to supply them with information which could be used for

this purpose. The advisability of writing a standard, now or eventually, is a matter upon which we cannot properly pass judgment. Likewise, we do not believe it is appropriate for us to try to settle the issue of just how far a standard should go in regulating display design. That is, how restrictive and how permissive it ought to be.

To repeat, our main endeavor has been to assemble and document information presently available in this field. This has been supplemented with what we have learned from conversations with others who have experience in display design and research. We have tried to present certain controversial subjects impartially and to intrude our personal views and the results of our own experience only insofar as they will contribute to an understanding of the problems. In those areas where more research seems needed we have singled out specific topics for research and investigation. Above all, we have tried to tailor this report to the needs of those who must deal with the problem of standardization, but we have also kept in mind the designers who must develop displays for future military aircraft and those who will carry on research in this field.

CHAPTER II - DISPLAY CATEGORIES

DEFINITIONS

At the outset, the term *electronic and optically generated displays* requires some clarification. Generally speaking, electronic and optically generated displays (E/O displays) are those devices by which an image is produced electronically and presented to the observer either directly on the image generating surface or indirectly through an optical projection system. The most common E/O display device is the cathode ray tube, but other image producing techniques are feasible, and a few, such as electroluminescence and lasers, have reached advanced stages of development. However, because of the historical importance of the CRT and because of the preponderance of present display designs which make use of the CRT, E/O displays may be thought of as primarily CRT displays.

As used in this report, the term E/O display is restricted to those devices used in aircraft by the pilot for the purposes of flight or mission control. This includes command and attitude displays, navigation displays, tactical information presentations, and weapon delivery displays. Displays used by crew members other than the pilot and co-pilot and those used by ground operators, even though similar in the method of generation or in the use to which they are put, are not classified as E/O displays. Thus, displays such as those used by radar observers, navigators, air traffic controllers, or tactical data system controllers are excluded from consideration. Obviously, this distinction is somewhat artificial. It would be hard to make a case for any real difference between a navigation display used by a pilot and a similar device used by another crew member, who does not happen to be a pilot, seated adjacent to him in the cockpit. In restricting E/O displays to mean airborne displays used by the pilot we wish only to narrow our field of interest to manageable proportions and to avoid excursions into fields that have already been amply treated by others. Clearly, some of the findings of this study will also have relevance to other types of displays, electronic and otherwise. If we neglect to point out these relationships in passing, it is only because we are sure they are already apparent to the reader.

To some the term E/O displays may be objectionable, and we must admit to a certain amount of dissatisfaction with it ourselves. Unfortunately, there appears to be no entirely suitable substitute as a generic name for this type of display. CRT display will not do since E/O displays may make use of some other image producing device. Carel (1965) has used the term *pictorial displays for flight*. While the simplicity and descriptiveness of this term are to be admired, it appears to include more kinds of displays than those which are of concern to us here. For example, an electromechanical Attitude Director Indicator (ADI) or a roller map display

could be properly called a pictorial display for flight. Yet, neither falls within our definition of E/O display because the images are not electronically generated. Similarly, an opto-mechanical display, such as the head-up display recently developed in France, would fall within the pictorial display classification but must be excluded from the E/O display category since the image is created entirely by optical means. Terms such as integrated flight display, electronic command and attitude display, or flight and navigation display all must be rejected since they suggest a range of applications other than what we have in mind. For lack of any clearly superior alternative, we have adopted E/O display, which we shall take to mean any electronic image producing device provided for the use of the pilot for flight and mission control.

E/O displays consist essentially of a two-dimensional surface upon which the multiple dimensions of the conditions of flight are presented, and this fact offers a convenient method of categorizing E/O displays. Thus, if the display surface represents a projection of the aircraft situation upon an imaginary vertical plane ahead of the aircraft, it is called a *vertical situation display*. If the display represents a projection of the situation upon a horizontal plane beneath the aircraft, it is a *horizontal situation display*. It should be noted that the designations *horizontal* and *vertical* have nothing to do with the plane in which the display is mounted in the aircraft; they refer to the reference planes upon which the real world situation is represented.

In a vertical situation display (VSD) the basic dimensions are azimuth and elevation. Lateral displacement, or translation, of display elements signifies change in aircraft heading or horizontal flight path. Vertical translation of display elements represents change in pitch or vertical flight path. Rotation of display elements denotes movement of the aircraft about the roll axis. In a horizontal situation display (HSD) the aircraft is represented as seen from above looking down on a horizontal earth plane. The frame of reference of the HSD may be either a cartesian coordinate system, like that of a map, or a polar coordinate system (rho-theta) in which the aircraft position is always at the pole. In the case of either HSDs or VSDs the additional dimensions of the flight situation may be represented either by means of geometric perspective or by coding schemes such as size, shape, degree of detail, color, and so forth.

Another method of classifying E/O displays is according to the manner in which they are viewed. For some displays the display surface or image-producing medium is viewed directly. That is, the observer looks directly at the surface upon which the symbols are written. These we shall designate *direct view displays*. For other displays the image is generated at some location out of the observer's direct view and projected, through an optical system, to some more suitable viewing location. These we shall call *projected displays*. Since projected displays are usually collimated light displays projected on a transparent surface, such as a combining glass or windshield, they are sometimes called *head-up displays* or *see-through displays*. With such displays the symbols appear to be at infinity, superimposed upon the real world view through the windshield.

The term head-up display (HUD) is expressive and has gained currency as a designation for projected, collimated light, see-through displays. For this reason we shall use it more or less synonymously with projected vertical situation display. However, there are certain cautions which should be observed about this and the other terms used above. For instance, a head-up display is not necessarily a projected display. It could be a direct view display so mounted that it is in the pilot's line of sight when looking out of the aircraft. In fact, such a display is currently under evaluation at the NASA Ames Research Center. Conversely, a projected display is not of necessity, a see-through or head-up display. It could be a projection of symbols onto an opaque viewing screen, *i.e.*, somewhat like a motion picture projection, so situated that the pilot's head is down in the cockpit when viewing the display. Such a device has also undergone evaluation at one time. At the risk of creating confusion, we can also introduce as an example the E/O display now under development at Bell Helicopter Company with which the pilot, by means of a head-mounted miniature CRT and projection system, receives a view of the world as seen by an externally mounted television camera. Such a display is both head-up and head-down. It is projected but not see-through because the pilot has no view other than that afforded by the TV camera, *i.e.*, the TV image is not superimposed on the real world but is a substitute for the real world, much like that seen on a direct view display. Other instances of hybrids and hard-to-classify displays could be cited, but there is no advantage in belaboring the point.

Here, again, we are confronted with inadequate terminology, which from a purist point of view is objectionable. However, since many of these terms are already in common use, we are obliged - somewhat ruefully - to accept matters more or less as they are and make the best of them. It is not our purpose to try to establish absolute and mutually exclusive categories, but rather to arrive at some working terminology to serve us in the succeeding chapters. We shall, therefore, employ *direct view* and *projected*, with the definitions given above, as basic categories of E/O displays. These terms, at least, have the advantage of brevity and of calling attention to an essential difference between the two types of displays. We shall also employ the VSD-HSD dichotomy discussed earlier. Thus, a display may be described as a direct view VSD or a projected VSD. *Head-up display*, unless otherwise noted, shall refer to a projected VSD.

At times it is useful to distinguish among displays on the basis of the technique by which the image is generated, *i.e.*, television raster, line written (sometimes called lissajous or calligraphic symbol generation), or electroluminescence. These techniques will be defined in the context of a later discussion in Chapter V. For certain special display applications, a distinction can also be made on the basis of the type of signal or sensor input which provides information for the display. Thus, one can speak of a radar, IR, laser, or X-ray display; and, if the display can present data from more than one such source, either sequentially or in combination, it is referred to as a multisensor display.

To familiarize the reader with several terms as we shall use them and to give an overview of the types of displays with which this report deals, Figure 1 contains a sample of the kinds of E/O displays now in use or under development. Since the samples are intended to be illustrative of types, the displays are not identified except by generic names. A more detailed description and analysis of some of the E/O displays actually designed for present day aircraft will be presented in Chapter III. For additional definitions of terms used in this report see the glossary in Appendix B.

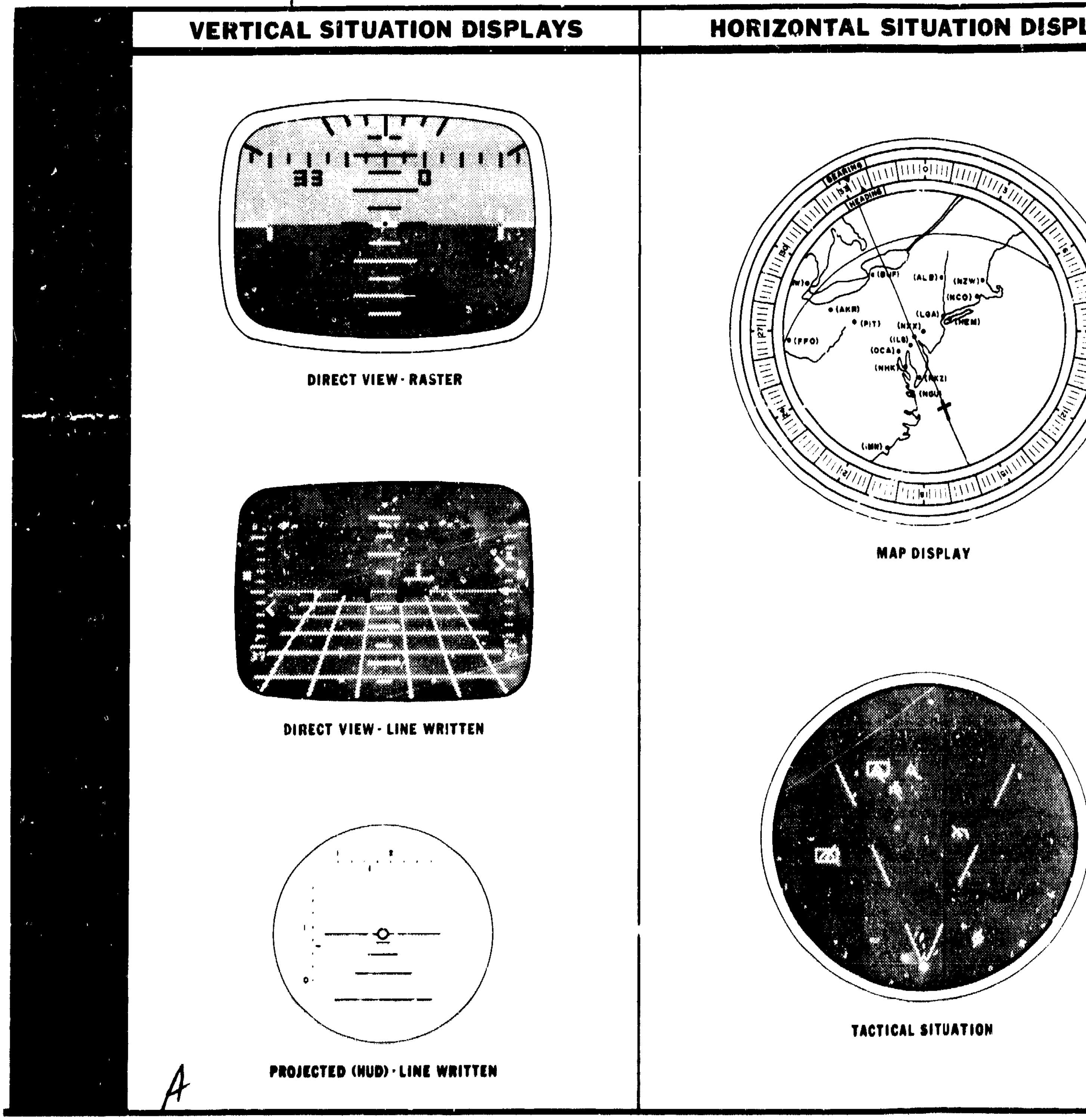
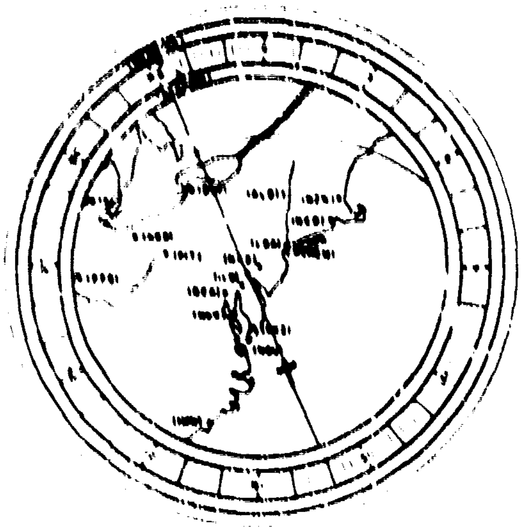


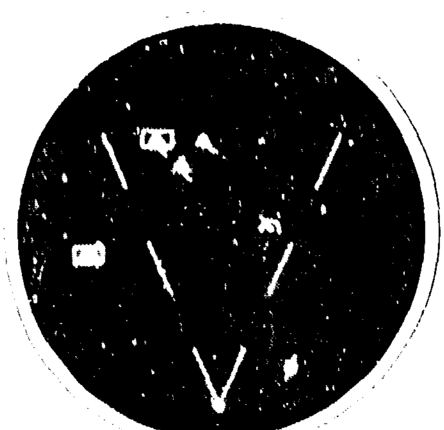
Figure 1 TYPES OF E/O DISPLAYS

2

HORIZONTAL SITUATION DISPLAYS

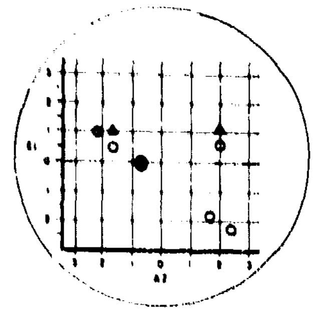


MAP DISPLAY

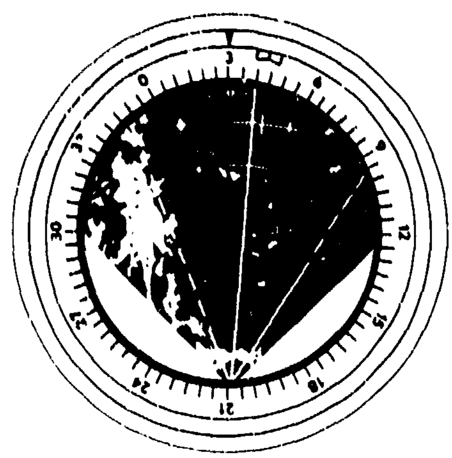


TACTICAL SITUATION

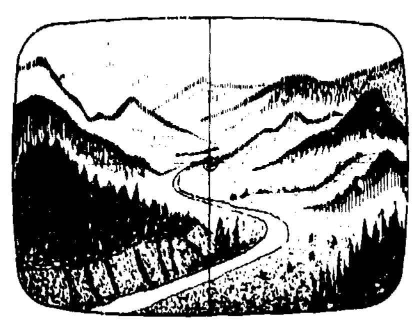
SPECIAL DISPLAYS



MULTISENSOR (RADAR/IR)



RADAR - PPI



TV DISPLAY

B

E/O DISPLAYS

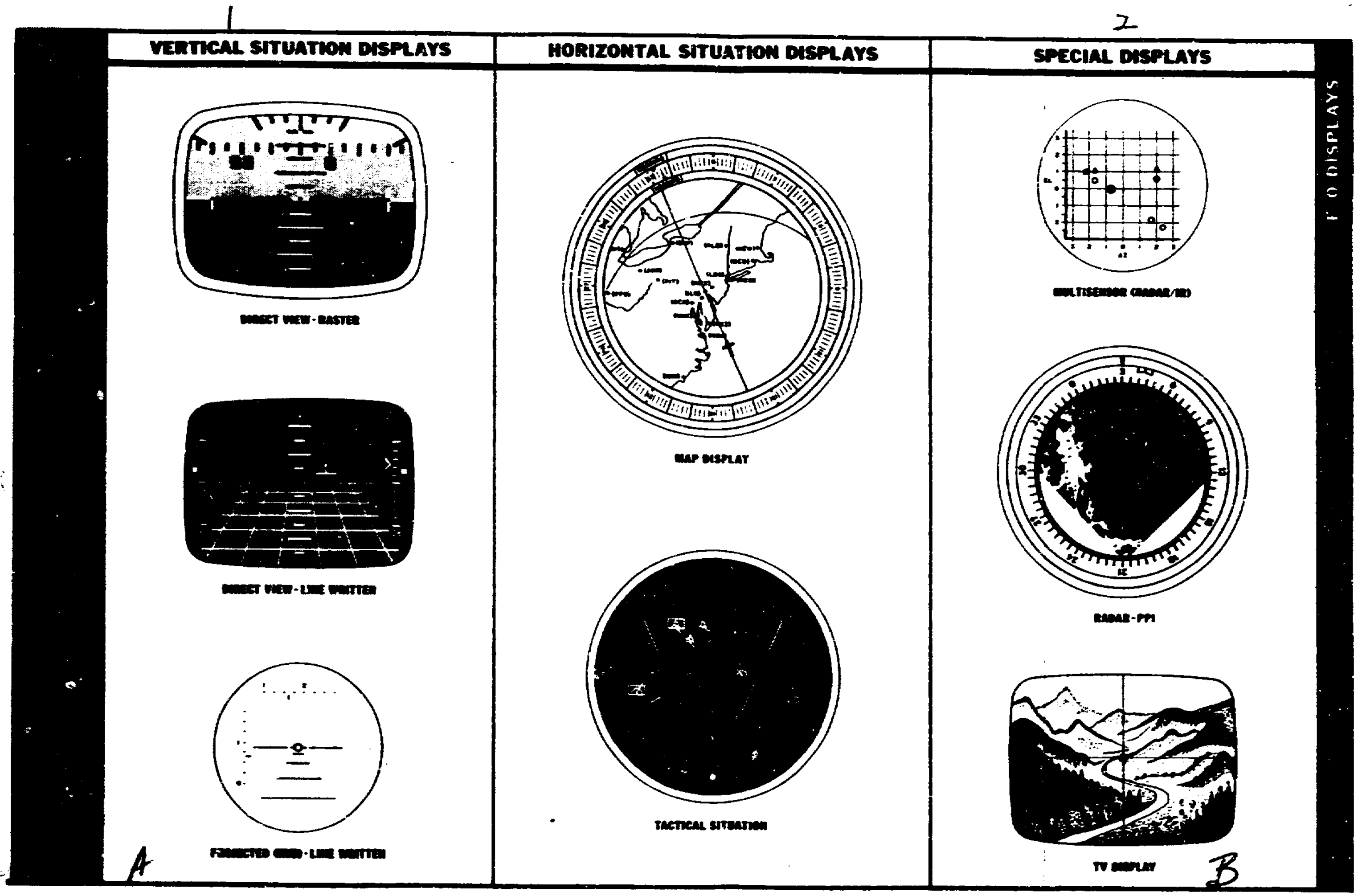


Figure 1 TYPES OF E/O DISPLAYS

DIRECT VIEW VERTICAL SITUATION DISPLAYS

Historically, the evolution of the direct view vertical situation display has been linked with the contact analog concept. It was not until the advent of compact, reliable, airborne CRTs that the realization of the contact analog concept became possible for aircraft displays. The contact analog display, as its name suggests, is a pictorial representation (or analog) of the real world view which the pilot would have under conditions of visual contact (VFR) flight. Two points must be emphasized. The contact analog is not a camera image or a televised view of the real world scene; it is a wholly artificial recreation of the real world. Second, every detail of the real world is not rendered in the contact analog presentation; it is a selective, abstract, and stylized picture of the real world. Carel (1965) defines the contact analog display as a "*point perspective projection of a three-dimensional model* (of the real world) *to a picture plane.*" Note that it is a projection of a model, not a projection of the real world itself (as would be the case in a televised picture of the real world). Thus, there are two steps of abstraction: from the real world to the model and from the model to the pictorial display. Whereas certain detail and pictorial realism may be sacrificed in this dual abstraction, there is one respect in which the contact analog display remains completely faithful to the real world. All the display elements obey the same laws of motion and perspective as their real world counterparts. In this sense, it is a true and full analog of the real world.

The underlying rationale of the contact analog emphasizes that a pilot can fly an aircraft solely by visual cues from the extra-cockpit environment. In fact, most of the instruments which have been introduced into aircraft have been put there to help the pilot manage the situation when he cannot see the real world because of darkness or weather. The contact analog, thus, becomes the means of recreating VFR day cues within the cockpit at all times. Because there is compatibility between the real world visual cues and those of the contact analog display, the pilot will have no difficulty in adapting from one to the other. Geometric relationships and cues of size, distance, and motion are the same within the cockpit and without; and the pilot's interpretive tasks on instruments or VFR are, theoretically at least, identical.

The contact analog offers many advantages as a pilot information display. Because of the "naturalness" of the presentation, it reduces ambiguity and uncertainty about the attitude and path of the aircraft. For the same reason it is relatively easy for the pilot to maintain his three-dimensional orientation in all flight situations. Because the contact analog affords an integrated and coherent presentation of information, it is conceptually simple to learn and to use. There are some, however, who find fault with the contact analog concept and with the underlying analysis of the pilot's perceptual and information processing tasks.

The critics of the contact analog have two major objections. First, they contend that the contact analog tends to overemphasize pictorial realism,

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i.e. there is too great a concern with creating a veridical real world picture—with its full range of visual cues - within the display framework. They point out that the real world contains many cues that are irrelevant, some that are redundant, and a few that are confusing or ambiguous. The pilot's basic task, they continue, is how to interpret and integrate this mass of information. By recreating on the display the world as it might be perceived outside the aircraft, one has not simplified the pilot's task but merely duplicated his source of information. The proper purpose of a display, they conclude, is not to copy the real world in all its blooming buzzing confusion but to select for display that information relevant to the task and to structure it meaningfully.

The point is well taken, and - surprisingly enough - many advocates of the contact analog display would heartily agree. They claim that this is exactly the point of the contact analog and that the fault lies not with the contact analog concept as originally conceived but with those who subsequently misunderstood it or misapplied it to display design. The fact remains, however, that the contact analog is basically pictorial, as opposed to symbolic, and that pictorial realism has tended to become an end in itself in some cases.

An even more serious objection has to do with the nature of the information available from real world visual cues. While it is true that most of the information necessary to control the aircraft is embedded in the visually perceived real world situation, it is not true that the information is readily available in its most useful form and with sufficient clarity and precision to meet the demands of controlling a situation as complex as that of an aircraft in flight. The pilot's task involves more than qualitative judgments; he must also deal with quantitative information. His task calls for attaining and holding certain absolute, quantitative values and for controlling dynamic factors such as rate and acceleration. The real world, and hence any display which reproduces it in pictorial fashion, is relatively poor as an immediate and precise reference for these kinds of information, especially rate and higher order derivatives.

As an alternative to the contact analog display, two major choices are available. With one of these, the vertical situation display retains certain pictorial features, however in highly stylized and abstract form. Pictorial realism is sacrificed in the interest of creating symbols which convey the real world situation in qualitative and quantitative terms. This may be done by simplifying real world cues, by distorting or exaggerating them to obtain greater clarity and precision, and even by adding display elements which have no direct counterpart in the real world as visually perceived. Proponents of this type of display contend that, while pictorial realism has its uses, faithful rendition of the underlying structure of the real world is of much greater value. With this display, the real world is stripped down to its bare essentials; hence the name *skeletal display*. Carel (1965) characterizes the skeletal display as one which shows *"the relationships between a set of inherently related variables by use of a pictorial code."* More important, since flight is essentially dynamic, it is necessary to create a display whose kinematics are like that of the external visual environment. Carel summarizes the point thus:

"...the way a symbol moves and its relationship to other symbols and their movements is more important than what the individual symbols look like statically. ...Symbol kinematics are just as important as symbol physiognomy."

In all fairness, it should be pointed out that the display concept outlined above is not considered by its originators as diametrically opposed to the contact analog. Rather, they conceive of displays as a continuum, with the "literal", *i.e.*, photographic, display at one extreme and at the other the "skeletal" display such as described above. The classic contact analog display falls somewhere about midway along this continuum of literalness.

A second major alternative to the contact analog is to be found in the type of display which we shall call the *instrument analog*. This represents an approach to display design which is completely different from that of the contact analog or skeletal displays described above. The display is thought of, not so much as a pictorial representation of the real world, but as a multipurpose instrument. The proponents of this kind of display contend that the several basic instruments now in aircraft cockpits are well designed and entirely suited to their purpose. They provide the pilot with the information he needs, in the required form, and with appropriate scaling and accuracy. The reasons these instruments present a problem to the pilot is that they are dispersed throughout a rather large area in the cockpit and that each is a single purpose instrument. This creates the need for the pilot to develop a scan pattern to monitor the separate indicators and places on him the burden of selecting and integrating the information in light of the particular needs of the moment. In addition, because each instrument is designed for a special purpose, sometimes without reference to other instruments located in proximity, there may be inconsistencies or incompatibilities among them. The E/O display offers a solution to these problems in that it is capable of combining, in one rather small area, the indications of a half dozen or more separate instruments. Furthermore, because of the versatility of the E/O display medium, symbols and formats like that of any of these instruments can be duplicated on the display surface. Finally, through mode switching, it is possible to achieve different combinations of instruments or to change scaling as the flight situation may require. Thus, the E/O display becomes a multiparameter instrument which is modeled not upon the real world scene external to the aircraft but upon the instruments in the cockpit which indicate the actual parameters of aircraft performance. It may be thought of either as a replacement for the conventional instruments now in the cockpit or as a supplement to them, a microcosm which allows the pilot to monitor the general situation on one display and make excursions to conventional, single purpose instruments for vernier or more detailed readings.

The point to the foregoing discussion is not to argue for or against any of these design concepts. Rather, it is to indicate that different approaches are possible, each having merit. This discussion also serves to identify at the beginning the questions of what are VSDs to be an analog of and what degree of verisimilitude is needed. These are central issues in vertical situation display design and should be kept in mind as we proceed through the subsequent chapters where various aspects of this topic will be treated in greater detail, especially in Chapter IV under the heading Some Display Solutions.

PROJECTED VERTICAL SITUATION DISPLAYS

The usual projected vertical situation display, or head-up display, is a device whereby symbols are generated and passed through an optical system to project them on a transparent viewing surface in front of the pilot. The optical system includes a collimating lens so that the symbols are at optical infinity and angular relationships between the symbols and the real world scene can be preserved throughout the field of view. The result is that the symbols appear to be superimposed on their real world counterparts as seen through the windshield. For example, the symbol which represents the horizon would overlay the real horizon and would move with it as the aircraft attitude changed. The symbols thus serve to enhance location and identification of those elements of the visual field which will aid in control of the aircraft.

The foregoing presupposes a one-to-one relationship in movement, and perhaps in size as well, between the symbols and the counterpart objects of the external environment. However, the assumption that such a relationship is necessary, or even desirable, is subject to challenge. Early work by Roscoe (1952) and Campbell (1955) with periscope displays indicated that a magnification factor of about 1.2 led to optimum pilot performance. That is, a symbol dimension or displacement of 1.2° on the display corresponded to object size or movement of 1° in the real world, both measured as the angle subtended at the eye. Quite the opposite view is taken by other head-up display designers who hold that display ratios on the order of 1:3 or even 1:6 are not only usable but highly desirable in some cases. That is, 1° of symbol displacement on the display represents 3° or 6° of change in the position of an object in the external environment. The circumstances in which such compression factors may be called for are either when the field of view of the display is restricted or when the range of aircraft movement is relatively large in comparison with the field of view.

Here, again, our purpose is only to call attention to one of the paramount issues of display design. The topic deserves much more thorough treatment and a more careful exposition of the experimental evidence on all sides of the question. This will be deferred until Chapter IV where it will be taken up in the context of symbol dynamics and display format. In passing, however, it should be noted that the question of magnification is not confined to head-up displays. It is also pertinent to direct view vertical situation displays, especially the contact analog. Some experts contend that, to be a true contact analog, the display must not only be pictorial and faithful to the laws of motion and perspective, it must also be equal in angular dimension to the real world scene represented. That is, if the display represents a 20° x 20° view of the world, it must be of such size and so located that it subtends a field of 20° x 20° of visual angle. We raise the problem in connection with head-up displays only because this is where the issue is most sharply joined. The see-through nature of head-up displays makes it possible to see both the real world scene and the

artificial representation of that scene at the same time. If there is any difficulty which may arise from a disparity between the real world and the display, it is most likely to manifest itself in a situation where the two are seen in superposition.

HORIZONTAL SITUATION DISPLAYS

By contrast with vertical situation displays, the field of horizontal situation displays is a relatively placid area, free of much of the acrimony which seems to characterize debates about basic issues in vertical situation displays. This is not to suggest the HSD designers are more reasonable or even-tempered than their VSD colleagues. There are questionable areas and differences of opinion, but the discussion seems to move at a slower pace. In part this may be because HSDs are a somewhat neglected area, a little less glamorous and likely to draw fire than VSDs. In part, too, it may stem from basic differences in the horizontal and vertical situations of the aircraft. Because the aircraft is somewhat less maneuverable in the horizontal plane, change occurs rather slowly in comparison with the vertical situation. Also, the geographic area covered by the HSD is usually so broad and the scaling of the display is such that the movement of symbols on the display is relatively slow. Hence, the consequences of misinterpretation or misdirection are less immediate, and perhaps less dangerous, than with the VSD and, therefore, less likely to create excitement or controversy among display designers. It may also be that, because the field of HSDs is somewhat older, there has been more time for empirical evidence on some of the basic issues to accumulate. The literature does seem, at least, to reflect a general understanding that one type of HSD is not inherently better than another, only better for a given purpose. This is not to suggest that there is complacency on the topic of HSDs. A misdirected pilot cannot very well perform his mission, and a lost pilot is still a pilot in trouble. There is clear recognition by all that everything possible should be done to provide the pilot with a display to help him maintain orientation and direction in the navigational or tactical situation.

Be that as it may, there are still several open questions in connection with horizontal situation displays. Perhaps the most fundamental of these concerns the dynamics and frame of reference of the display. Specifically, what part of the display should move? Should the map move and the aircraft reference symbol remain stationary, or should the aircraft symbol move across a stationary map which is changed from time to time as the symbol nears the edge of the display? Interlocked with this are questions of which type of coordinate system to use (cartesian or polar) and how should the map be oriented (toward north or along the ground track). Parenthetically, it should be noted that the term "map" as used here does not necessarily mean a topographical map or airman's chart printed on paper. It means any representation of the horizontal situation in which symbols are "mapped", in the mathematical sense, to objects in the external environment. These objects may be on the ground or airborne. This whole issue of display movement and a frame of reference is an important one, every bit as important as the issues of pictorial realism and display compression-magnification in the VSD field. We will address ourselves to it in later parts of the report, principally in Chapter IV.

Some other questions in the HSD area are related to the techniques of display generation and mechanization. A great variety of methods is available. Some HSDs are essentially mechanical devices in which a printed map or chart is combined with indicators of position and course. Others make use of projection techniques to present a film map in conjunction with symbols which may be mechanical or projected like the map itself. Neither of these kinds of HSDs is of concern to us here, except tangentially in that they embody the same basic display principles as E/O displays or in that the legibility of symbols may be affected by an optical projection system. Our main concern is with those HSDs which are wholly or partially generated by electronic means. Much of the discussion of display characteristics in Chapter V applies to HSDs and VSDs equally. There is no intent to slight HSDs, even though the majority of examples in that chapter are drawn from VSDs. It is simply because there were more examples of VSDs available to us.

Some choose to make a distinction between navigational or tactical HSDs, either along the lines that a navigation display is an earth map and the tactical display is an air map or along the lines that the navigation display is stored information and the tactical display is based on freshly generated data. Frankly, either of these distinctions seems artificial. Whether for navigation or tactical employment of the aircraft, both types of displays are maps or representations of the horizontal situation. The displays may contain slightly different kinds of information or be somewhat different in format because of the various uses to which they are put, but this creates no inherent differences in the displays themselves.

As a final commentary on horizontal situation displays, we would like to draw attention to published works in this area which seem to be of particular value. Certain parts of them will be discussed later, but we should like to point them out here because they are excellent summations of areas which overlap our own. The proceedings of the 1966 JANAIR symposium on aeronautical charts and map displays (JANAIR 1966) is a recent and highly informative review of the HSD field. Honigfeld (1964) is a comprehensive review and authoritative commentary on symbology for radar displays. Roscoe (1967), while mainly a statement of the author's own views, is in our estimation a good succinct summary of the basic questions in HSD design. Finally, of course, there is Carel (1965) which has already been cited and which covers much the same ground as this report.

CHAPTER III - INFORMATION REQUIREMENTS

INTRODUCTION

In display design, the establishing of information requirements is a basic and early step. It provides a systematic method for determining the kinds of displays needed in the aircraft and for guiding the selection of format, display modes, and individual symbols. Although the method may be imperfectly implemented in practice, as noted by Carel (1965), it does not follow that the approach itself is bad or that analysis of information requirements is of no value to the designer. Analysis of information requirements is not necessarily the first step; there are other valid points from which to begin. But we must ultimately submit the display to analysis in terms of the operator's informational needs or the design will be void.

Information requirements can be developed in a number of ways. They can be stated broadly or in minute detail. They can be treated generically or restricted to a certain kind of aircraft, or even limited to a particular aircraft in just one maneuver or flight phase. In the case of E/O displays, which are usually designed for a particular aircraft, information requirements are customarily based on the performance of the vehicle and are often related to some nominal mission profile or breakdown into flight phases. In these circumstances, the aircraft development schedule, the availability of information about the aircraft system, hardware constraints, pilot acceptance, and so on tend to act as limits on the extent to which information requirements are formulated for the display design. Compromises in the depth and breadth of information requirements lists are understandably the rule in practice.

On the other hand, it is possible to derive a list of information requirements independent of the particular aircraft and of the design of a display for presenting this information. There have been several studies undertaken for this purpose, some of which will be discussed later (page 27 ff). The underlying assumption is that such a list, objectively and independently derive can serve as the basis for comparative evaluation of display designs. That is, one display design can be compared to another in terms of the number of information requirements that each satisfies. Supplementary considerations, such as cost effectiveness or effect on operator workload, can be introduced to give greater subtlety and sophistication to the evaluation. In theory, one should be able to determine systematically the merits of competing designs, the most parsimonious approach that does the job being deemed best. The crux is in deciding what "the job" is; and in practice the solution is usually found by taking the general requirements list and rendering it more and more specific to the technique of display mechanization and to the aircraft in which the display is to be installed.

The point is that neither the specific nor the general approach is entirely suitable for the purpose of this study which is, in part, to examine the question of standardizing E/O display content. The information requirements developed by the designers of a display for one aircraft cannot be used to set a standard for a display, even a similar one, in another aircraft. Likewise, no single general requirements list appears suitable across the board for all aircraft, all missions, and all kinds of displays.

The method we shall use here is to approach the problem of formulating information requirements from opposite directions, working from the general and from the specific, in an attempt to find a suitable middle ground. We shall start by considering several studies which formulate information requirements in a general way, *i.e.* without regard to a particular aircraft design or display mechanization. Our goal is to identify what informational needs are agreed upon as common to all aircraft and what are common within certain classes of aircraft. Next, we shall analyze E/O displays for eight different aircraft (eleven displays in all) to see what information requirements are actually satisfied and to what extent there is *de facto* agreement among display designers about information requirements. (It is assumed, for the sake of comparison, that the information content of each display represents what the designers believe to be the pilot's needs and that designs have originated from more or less independent sources.) The results of the two analyses will then be compared and synthesized into a composite list of information requirements for VSDs and HSDs. The analytic paradigm used in this chapter is shown in the diagram in Figure 2.

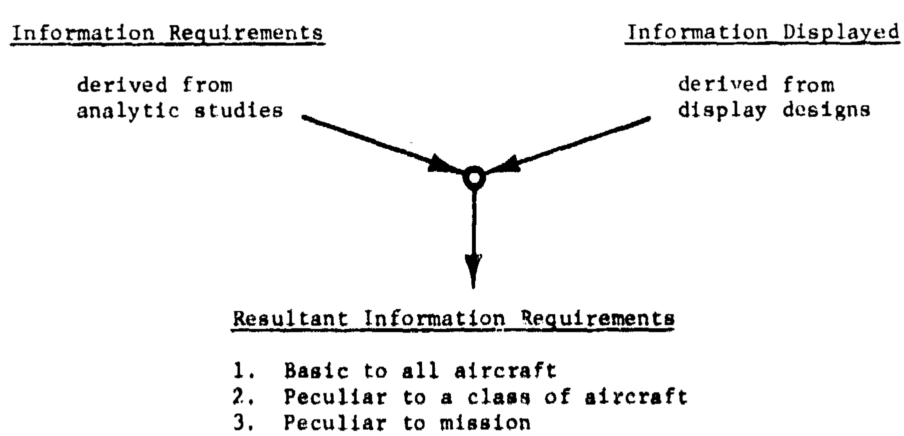

Figure 2. ANALYTIC PARADIGM FOR INFORMATION REQUIREMENTS

It is not our intention to offer a single summation of all the studies and displays which we examine. Our task is to evaluate, to identify conflicting points of view, to resolve differences when we can, and to offer our own comments when appropriate. We cannot hope to be comprehensive; time and resources have not permitted us to include all the work that has been done in this area. Of the available general information requirements analyses we have chosen those which seem most thorough as well as those which are more briefly treated. In the selection of E/O displays for analysis we have been restricted to those for which detailed specifications or design descriptions have been published. However, in both instances the samples are large and, we believe, representative of the field. As much as possible, we have tried to present not only our conclusions but also the evidence upon which they are based.

In part we are using existing display designs as a model for deriving information requirements. In this connection two points should be emphasized. First, poor design can and does occur. No amount of analysis and study will guarantee that designers will interpret the results correctly and choose their symbols wisely. Second, displays sometimes evolve without benefit of analysis of man-machine system requirements. What exists in the hardware is not necessarily the result of careful and penetrating study. Expediency and best-guess approximations often prevail over empirical research. It should also be noted that display design tends to be imitative. A successful display design often sets a style and influences the development of later displays, even those for purposes different from that of the original.

The information content of contemporary E/O displays has resulted from design efforts in a variety of projects, each of which has been geared to a particular application and to particular constraints. Many displays are limited in what they can, and desirably could, contain by the availability of information in the interface or by a lack of appropriate sensors. Our analysis of contemporary display content reflects that which exists. We are not able to reconstruct the causal relationships, constraints, interface problems, and design goals which have led to display content decisions for existing E/O displays. It is doubtful that anyone could. Nevertheless, major display design efforts may be presumed to reflect that which designers considered to be the most important information requirements, and from this a certain amount of generalization is possible.

It is our belief that the information requirements developed in this chapter could serve as the basis for a standard, at least a preliminary one, which attempts to develop a common display language. However, the reader is free to examine the evidence for himself and to accept or reject our conclusions on their merits. If nothing else, we hope that this study will stimulate others to examine the question and to improve upon our interpretation. We believe it fruitful to develop the information in this way even though there may be disagreement about its meaning and the validity of generalizing from it.

AIRCRAFT TYPE AND MISSION

In September 1962 the Department of Defense established a new system of military aircraft designation. Eight basic categories of mission or aircraft type are specified:

A - Attack

B - Bomber

C - Cargo/Transport

E - Special Electronic Installation

F - Fighter

H - Helicopter

K - Tanker

V - V/STOL

It should be emphasized that the above are basic mission types; additional letter designators, which are used to indicate modified mission and status, are not included in this breakdown.

Of the eight, six pertain to fixed wing aircraft which differ primarily in terms of mission. Of the remaining two, H (Helicopter) is clearly a class by itself by virtue of the unique dynamics and control properties associated with the rotary wing. Although the V/STOL class is akin to fixed wing aircraft in many respects, it differs in takeoff and landing (where it is more like a helicopter) and thus warrants independent listing. For our purposes then, the above list can be reduced to three categories:

- FIXED WING
- V/STOL
- ROTARY WING

Admittedly, there are differences among the various types of fixed wing aircraft. However, if we exclude mission considerations, the differences among fixed wing aircraft in information requirements and control/display relationships tend to be rather small when compared to the differences

between the fixed wing class and either the rotary wing or V/STOL classes.

Regardless of aircraft type, there are certain activities or flight phases which are common and which impose special informational needs. Three of these will be considered in the following analysis of information requirements.

- TAKEOFF - This includes takeoff from an airfield and launch from an aircraft carrier and extends through the initial part of the climbout to cruise or en route altitude.
- EN ROUTE - This includes that portion of the mission spent going to the destination or cruising at altitude.
- LANDING - This includes penetration from altitude, initial approach and final approach.

There are other types of activity not specifically included in the above which deserve consideration because of the special problems they pose in terms of information requirements and display design. These are weapon delivery (either air-to-air or air-to-surface) and terrain avoidance or terrain following. They are not included in the analysis of information requirements but are taken up, in a less formal way, in a separate section at the end of the chapter.

CONTEMPORARY E/O DISPLAYS

Table 1 lists the more significant contemporary E/O displays. These range from the earliest operational VSD, in the A-6A aircraft, to displays which are still in the preliminary stages of development. With the exception of the F-111A Mark II avionics system, the details of which are classified, all of the displays in Table 1 will be analyzed for information content in this chapter. In addition, a tabulation of display characteristics such as resolution, phosphor color, filters, luminance, and gray tones is presented at the end of Chapter V (Table 23). Appendix C contains illustrations and brief descriptions of other E/O displays which we were unable to include in the body of this report because there was insufficient information available to us about the design and intended use of these devices.

TABLE 1 - CONTEMPORARY E/O DISPLAYS AND APPLICATIONS

E/O DISPLAY	TYPE	MODES	AIRCRAFT	A/C TYPE-MISSION	CREW	OTHER SPECIFIED AVIONICS
ADI Analog Display Indicator (formerly VDI)	VSD • Direct View • Raster • Head Down	• Contact Analog • Terrain Avoidance • E-Scan • Standby • Test	A-6A	• Navy/Marine Corps • Fixed Wing, Long Range, Long Loiter, Low Level Attack Bomber, Subsonic Jet • Night, All Weather	• Pilot • Bombardier/Nav	• Doppler & Inertial Nav • Terrain Avoidance Radar • Air Data Computer • DIANE (digital) Computer
VDIG Vertical Display Indicator Group (formerly V/HUD)	VSD • Direct View • Raster • Head Down (DVI) VSD • Projected • Line Written • Head-up (HUD)	COMMAND MODES • Inertial Nav • TACAN • Weapons Computer (PMS) • Data Link (NTDS & ATDS) • Auto. Carrier Landing DISPLAY MODES • Takeoff • Flight • Landing • Attitude Only • Alternate Weapon • Tactical Display • Test • Terrain Avoidance	F-111B	• Navy, Carrier Based • Variable Wing, Fighter, Interceptor, Bomber • Fleet Air Defense, Tactical Support • Subsonic & Supersonic Operation	• Pilot • Missile Control Officer	• Inertial Bomb/Nav/Computer System • Terrain Following Radar • TACAN • Data Link (NTDS, ATDS) • Air Data Computer • Carrier Landing System • Scan Converter
TID Tactical Information Display (Phoenix Missile System)	HSD • Direct View • Radar • Head Down	• Air to Air • Low Pulse Rate (Terr. Avoid. & Visual Ident.)				• Search Radar • IR
DDD Detailed Data Display (Phoenix Missile System)	MSD • Direct View • Radar or IR • Head Down • Multisensor	• C-scan (Az-El) • Range Rate-Az • TID Expand (PPI) Range-Az				
A-7D HUD	VSD • Projected • Line Written • Head-up	• Enroute • Attack • Landing	A-7D,E	• Navy/Air Force/Marine Corps • Fixed Wing, Subsonic, Jet, Light Attack Aircraft • Close Air Support • Land or Carrier Based	• Pilot	• Doppler Nav Radar • TACAN • Air Data Computer • FLAS Forward Looking Radar • Terrain Avoidance Radar • Terrain Following Radar • Nav Computer • Roller Map Display
AAAIS Advanced Army Aircraft Instrumentation System	VSD • Direct View • Raster • Head Down	• Nav Mode - Doppler - Air Data - Nav Ref • Flight Path Attitude - Max Endur - Max Range - Present alt - Alt select - Vert Rate - Terr Foll • Flight Path Course - Takeoff - Nav Course - Present Course - BRG Command	Installed in F-50 (Twin Bonanza), NU-8E (Seminole) for test & evaluation	• Test and Evaluation • Army Fixed Wing & V/STOL • Rotary Wing Applications Uncertain	• Pilot	• Central Digital Computer • Vertical Gyro • Doppler Radar • Forward Looking Radar • Air Data Computer • DME • ILS • Fuel Flow • Map Scanner • AN/APN-149 (modified) Terrain & Obstacle Avoidance System • Voice Warning

A.

DDD Detailed Data Display (Phoenix Missile System)	MSD • Direct View • Radar or IR • Head Down • Multisensor	• C-scan (Az-El) • Range Rate-Az • TID Expand (PPI) Range-Az				
A-7D HUD	VSD • Projected • Line Written • Head-up	• Enroute • Attack • Landing	A-7D,E	• Navy/Air Force/Marine Corps • Fixed Wing, Subsonic, Jet, Light Attack Aircraft • Close Air Support • Land or Carrier Based	• Pilot	• Doppler Nav Radar • TACAN • Air Data Computer • ILAS Forward Looking Radar • Terrain Avoidance Radar • Terrain Following Radar • Nav Computer • Roller Map Display
AAAIS Advanced Army Aircraft Instrumentation System	VSD • Direct View • Raster • Head Down	• Nav Mode - Doppler - Air Data - Nav Ref • Flight Path Attitude - Max Endur - Max Range - Present alt - Alt select - Vert Rate - Terr Foll • Flight Path Course - Takeoff - Nav Course - Present Course - BRG Command - Homing - Land	Installed in F-50 (Twin Bonanza), NU-8E (Seminole) for test & evaluation	• Test and Evaluation • Army Fixed Wing & V/STOL • Rotary Wing Applications Uncertain	• Pilot	• Central Digital Computer • Vertical Gyro • Doppler Radar • Forward Looking Radar • Air Data Computer • DME • ILS • Fuel Flow • Map Scanner • AN/APN-149 (modified) Terrain & Obstacle Avoidance System • Voice Warning
	HSD • Direct View • Raster • Radar	• Fixed Map • Moving Map • TCPPI • Ground Mapping				
IHAS Integrated Helicopter Avionics System	VSD • Direct View • Line Written		AH-56, CH52, CH53A, CH46A, CH47A	• Navy/Marine Corps/Army • Rotary Wing All Weather • Terrain Avoidance, Doppler Nav, Station Keeping Capability • Fire Support (Army AH-56) (AH-56 modifications to IHAS not listed)	• Pilot • Co-pilot	• Doppler Nav Radar • Station Keeping Radar • Forward Looking Radar • Nav Computers • Inertial Heading Reference (AN/ASN-50 & aligning gyro)
	HSD • Direct View • Raster • Head Down	• Navigation (Map) • Profilescope (Terr. Avoid.) • Mapping (Radar Search)				
ILAAS Integraced Light Attack Avionics System	VSD • Raster • Head Down • Direct View	• Flight Situation • Low Altitude (Terr. Avoid.) • Test	VFAX (1970 Package)	• High Performance Fighter/ Attack aircraft • Carrier Based	Crew not Specified	• Multimode Radar • Central Air Data Computer Inertial Reference Sets • Data Conversion Equip • Doppler Navigation Radar
	HSD • Direct View • Head Down	• PPI Radar • Missile TV • E-Scan • Threat Bearing • Chart • Test				
	HUD	• Enroute • Data Link • Data Link (Carrier Landing) • Low Altitude (Terr. Avoid.) • Weapon Delivery • Standby • Test				

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INFORMATION REQUIREMENTS STUDIES

It is highly unlikely that there will ever be a single, empirically derived list of information requirements for vertical and horizontal situation displays which is both generally accepted and truly comprehensive. This is true not only because of the variability of aircraft types and missions but also because of the variety of purposes for which information requirement studies are conducted and the differences in the level of detail to which they are carried out. On the other hand, one of the goals of standardization is to develop, insofar as possible, a common display language in terms of information content and form. Thus, we are obliged to seek out those areas in which there is substantial agreement about the information needed to control and direct aircraft and to formalize this information in such a way that it can guide the design of integrated flight and navigation displays. The paradigm shown in Figure 2 describes our attempt to make such an identification. We are fully aware of the methodological shortcomings of this approach. However, in the absence of any precise and workable technique for establishing information requirements deductively, we have chosen to proceed on an empirical basis.

As a further reservation, it is necessary to point out the dissimilarities among the studies from which we have made a generalization. That is, we are guilty to some extent of comparing apples and oranges in that not all of the information requirement studies are alike in their method and their purpose. Some are purely analytic, some are syntheses of existing display designs, and one is a pilot opinion survey. Some apply to a certain class of aircraft, some apply to just one aircraft, and some apply to a particular display concept which may be used in more than one aircraft. Not all are as detached from hardware and mechanization constraints as one might like.

We have chosen, for example, to include a 1962 study for the Douglas Aircraft Company, conducted under ANIP sponsorship. This is representative of the kind of systematic analysis of pilot information requirements which should precede display design. We have also included a study by Baxter and Workman (1962). This is a composite list of the information content of five displays (Sperry, ARL, Bendix, Spectocom, and Douglas ANIP) and, therefore, is not truly an analysis of information requirements. Our view, however, is that their list is a comparatively early attempt to derive a consensus - an aim very much like our own - and may properly be considered a kind of analytic study. We have also used, from Carel (1965), three examples of information requirements lists which highlight differences in the scope and degree of specificity to be found among information requirements studies. We believe this is proper since our purpose is to cover as broad a range of opinions as possible and to show variety as well as agreement.

There are many pitfalls in making comparisons among the variety of studies we have selected, and generalization is a risky proposition at best. An obviously better solution would have been to use only analytic studies which

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are independent of a particular aircraft, or even aircraft type, and unconstrained by consideration of the way in which information is to be displayed. Unfortunately, there are all too few of these. We have been obliged instead to make use of what is available and to strive for impartiality through an eclectic approach. By presenting a wide and representative sample of information requirements lists drawn from available research literature we can hope to balance t diverse opinions and to compensate for individual flaws and biases.

The reports from which information requirements lists were chosen are given below in the order in which they appear in Table 2. Some cover all three flight phases: takeoff, en route, and landing. Some apply to landing only. Still others do not explicitly indicate the parts of flight to which they are applicabl . The code letters T, E, and L are used in all cases to indicate our judgment of the flight phases for which the particular list is appropriate. A précis is included for each report.

1. Douglas Aircraft Co. An Examination of Pilot Information Requirements. Prepared by Dunlap and Associates for Douglas Aircraft Co., Contract Nonr 1076(00), November 30, 1962, AD 401 662.

   (T, E, L) - A systematic analysis of pilot information requirements, done under ANIP sponsorship; includes a classification scheme, a weighting scheme to determine the importance of data to a specific task, and a control model.

2. Williams, P. R. and Kronholm, M. B. Technical Report on Simulation Studies of an Integrated Electronic Vertical Display. Norwalk Conn.: Norden, December 31, 1965, AD 629 157.

   (T, E, L) - JANAIR sponsored systematic analysis of information requirements as determined by mission requirements and aircraft performance; covers fixed wing, rotary wing, and VTOL aircraft.

3. Grumman Aircraft Engineering Corp. Recommended Pilot Displays. GAEC Report No. 9064. Bethpage, N.Y.: January 16, 1964.

   (T, E, L) - Information requirements for an interceptor/attack aircraft.

4. Soliday, S. M. and Milligan, J. R. Simulation of Low Altitude High Speed Mission Performance. Vol. II, Effectiveness of a Head-up Display for Take-off and Landing in a Fighter Aircraft. Columbus, Ohio: North American Aviation, Inc. Columbus Div., Tech. Report No. SEG-TR-66-67, Vol. II, February, 1967, AD 808 343L.

   (T, E, L) - Effectiveness of a HUD for a fighter aircraft, especially in takeoff and landing.

5. Sperry Gyroscope Co. Progress Report on Human Factors Analytical Study for Head-up Display System Development. Inertial Systems Div., Sperry Gyroscope Co., Great Neck, N.Y.: Report No. AB-1210-0008, August, 1963. AD 347 524 (Confidential).

(T, E, L) - Human factors analytical study for HUD.

6, 7. Semple, C. A. Jr., and Schwartz, R. W. Time Based Analysis of Control Activities and Information Requirements for V/STOL. WPAFB, Dayton, Ohio: Air Force Flight Dynamics Lab. Tech. Report No. AFFDL-TR-65-193. January, 1966.

6. (T, E, L) - Short field takeoff, en route, and landing requirements for V/STOL aircraft.

7. (T, L) - Vertical takeoff and landing requirements for V/STOL aircraft.

8. Baxter, J. R. Projected Symbolic Displays for General Aircraft. Melbourne, Australia: Aeronautical Research Laboratories, Australian Defense Scientific Service, ARL/HE 14. March, 1963, AD 428 683.

(L) - HUD information requirements for general aircraft.

9. Baxter, J. R. amd Workman, J. D. Review of Projected Displays of Flight Information and Recommendations for Further Development. Melbourne, Australia: Aeronautical Research Laboratories, Australian Defense Scientific Service, Human Engineering Report No. 2, August, 1962. AD 608 843.

(L) - Analysis of Sperry, ARL, Bendix, Spectocom, and Douglas ANIP displays for information content.

10. Behan, R. A., Smith, E. E., and Price, H. E. Pilot Acceptance Factors Related to Information Requirements and Display Concepts for All-weather Landing. Sherman Oaks, Calif.: Serendipity Associates, March, 1965. NASA CR-189.

(L) - Survey of pilot opinion on information requirements for all-weather landing.

11. Naish, J. M. Display Research and its Application to Civil Aircraft. Farnborough, England: Royal Aircraft Establishment. *Journal of Royal Aeronautical Society*, Vol. 69, October 1965, pp. 662-679.

(L) - The head-up display and its application to civil aviation.

12. Johnson, R. F. and Momiyama, T. S. Flight Test and Evaluation of the Spectocom Head-up Display. Patuxent River, Md.: Naval Air Test Center, NATC Report No. FT 2222-65R-64, December 1964.

(L) - Flight test and evaluation of Spectocom HUD in an A-5A aircraft.

13. Morrall, J. C. The Role of the Pilot in All-weather Operation. Farnborough, England: Royal Aircraft Establishment Tech. Memo. BLEU-123. June, 1966. AD 804 648.

(L) - Role of the pilot in all-weather landing with the Blind Landing Experimental Unit (BLEU) display.

14, 15, 16. Carel, W. L. Pictorial Displays for Flight. Culver City, Calif.: Hughes Aircraft Co., December, 1965. AD 627 669.

(L) - Three representative lists of information requirements from unidentified sources.

Information requirements from the above reports are listed in Table 2 under the categories: flight information, navigation information, airframe control surfaces, system status, and power and thrust. Each report is identified by the number given above. The terminology of the original report has been retained for the most part although in some cases we have altered it slightly for the sake of clarity or simplicity. In the final column on the right for each flight phase, under the symbol Σ, is the total number of reports which identify each item as a requirement for that flight phase. On the extreme right in the column headed T is the total number of reports which list the item as a requirement for at least one flight phase. Thus, if reports 11 and 12 list an item as a requirement for takeoff and reports 12, 13, and 14 list it for landing, the total in the Σ column for takeoff would be 2; in the Σ column for landing it would be 3; and under T the total would be 4.

Table 2 is, therefore, a tabulation of information requirements which are grouped under five categories according to three common flight phases. It shows the frequency with which items of information are specified as requirements in the source documents.

TABLE 2 - TABULATION OF INFORMATION REQUIREMENT STUDIES

INFORMATION REQUIREMENTS		TAKEOFF 1	2	3	4	5	6	7	Σ	EN ROUTE 1	2	3	4	5	6	Σ	LANDING 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Σ	T
FLIGHT INFORMATION																																		
Attitude	Pitch	X	X	X	X	X	X	X	7	X	X	X	X	X	X	6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16	16
	Roll	X	X	X	X	X	X	X	7	X	X	X	X	X	X	6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16	16
	Yaw	X					X	X	3	X					X	2	X					X	X										3	3
Pitch Trim		X	X						2	X	X					2	X	X										X				X	4	4
Angle of Attack	Actual			X		X	X	X	4					X		1			X		X	X	X								X	X	6	6
	Command					X			1					X		1					X							X					2	2
	Error					X			1					X		1					X							X					2	2
Altitude, Pressure	Actual	X				X			2					X	X	2		X			X				X							X	4	6
	Command					X			1					X		1																X	1	2
Altitude, Radar					X	X	X	X	4				X	X		2				X	X	X	X	X	X				X			X	8	8
Altitude, Unspecified	Actual	X		X					2	X	X	X				3	X		X							X	X			X	X		6	7
	Command	X							1	X		X				2	X													X	X		3	4
Vertical Velocity	Actual	X	X			X	X	X	5	X	X			X	X	4	X	X			X	X	X		X					X			7	7
	Command					X			1					X		1					X									[illegible]			2	2
Airspeed, True	Actual													X		1															X	X	2	3
	Command													X		1																X	1	2
Airspeed, Indicated	Actual				X	X	X	X	4				X	X		2				X	X	X	X			X						X	6	6
	Command				X	X			2				X	X		2				X	X												2	2
Airspeed, Unspecified	Actual	X	X	X					3	X	X	X				3	X	X	X											X	X		5	5
	Command	X							1	X		X				2	X													X	X		3	4
	Error																							X	X		X		X				4	4
Airspeed, Mach Number		X							1	X				X	X	3	X																1	3
Bank		X							1	X			X			2	X									X							2	3
Rate of Turn						X			1					X	X	2					X									X			2	3
Sideslip (Lateral Acceleration)			X						1		X			X		2		X															1	2
Steering	Command																														X	X	2	2
	Heading Command	X				X			2	X				X		2	X				X				X					X	X		5	5
	Heading Error				X	X			2				X	X		2				X	X			X			X	X	X				6	6
	Pitch Command				X				1				X			1				X				X			X	X	X				5	5
	Roll Command				X				1				X			1				X				X			X	X	X	X			6	6
Flight Path (Velocity Vector)	Actual				X	X			2				X	X		2		X		X	X			X	X				X				6	6
	Error				X	X			2				X	X		2				X	X												2	2
Vertical Glideslope Deviation																		X		X				X	X	X	X	X	X		X		9	9
Lateral Glideslope Deviation																		X		X				X	X	X	X	X	X		X		9	9
Heading Relative to Runway																	X								X								2	2
Distance Along Runway			X						1									X	X														2	2
Aiming Point																				X					X								2	2
Go-Around																				X												X	2	2
NAVIGATION INFORMATION																																		
Heading		X	X		X	X	X		5	X	X		X	X	X	5	X	X		X	X				X			X		X	X		8	9
Ground Track						X			1					X		1					X									X			2	2
Course																															X		1	1
Groundspeed		X							1	X				X	X	3	X				X		X							X			4	5
Aircraft Position	Geo. Ref.	X							1	X					X	2	X																1	2
	Mission Ref.									X					X	2	X																1	2
	Unspecified																													X	X		2	2
Range to Objective										X					X	2	X		X	X		X	X	X				X					7	7
Command Time to Objective										X						1	X	X															2	2
Topographic Obstruction										X						1														X			1	2
Dangerous Weather (Loc. Ref.)										X						1	X													X			2	2
Fuel Quantity		X						X	2	X		X		X	X	4	X		X											X			3	6
Fuel Flow Rate		X						X	2	X		X		X	X	4	X	X												X			3	6
Carrier Position								X	1					X		1														X	X		2	4
AIRFRAME CONTROL SURFACES																																		
Landing Gear Status		X							1								X				X									X			3	3
Drag Chute Position																	X				X												2	2
Speedbrake Position						X			1												X									X			2	2
Flap Position - Best						X			1																									1
Trim Condition - Best						X			1					X		1																		1
SYSTEM STATUS																																		
Warning, Caution, Advisory		X				X			2	X		X		X		3	X		X														2	3
POWER & THRUST																																		
Thrust	Actual	X				X			2	X				X		2	X				X												2	2
	Command					X			1					X		1					X												1	1
Engine RPM		X				X			2	X				X		2	X				X												2	2
Exhaust Gas Temperature		X				X			2					X		1					X												1	2
Gross Weight							X	X	2													X	X										2	2
Lift Engine Thrust Vector Angle*							X	X	2													X	X										2	2
Cruise Engine Thrust Vector Angle*							X	X	2													X	X										2	2
Lift Engine Power Setting*							X	X	2													X	X										2	2
Cruise Engine Power Setting*							X	X	2													X	X										2	2

* Applies to V/STOL Aircraft Only

Analysis of Information Requirements Studies

From Table 2 it would appear that, with a few exceptions, there is little agreement about the items of information required for flight and navigation. All the studies agree that attitude information (pitch and roll) is needed, but thereafter disagreements begin to emerge. Some of these disagreements, however, are more apparent than real because they stem from differences in terminology. For example, some reports speak of *heading command,* and others use the term *heading error.* With the exception of report 5 which makes a distinction between them, the two terms appear to be roughly synonymous, and 10 of the 16 reports call for one or the other. The agreement can be widened further still if we treat steering (in all its forms), flight path error, and vertical and lateral glideslope deviation as a single class of information. In landing, for example, 13 of 16 reports specify some form of steering or flight path guidance as an information requirement.

A second kind of apparent disagreement arises from differing views about the type of information to be used. That is, 3 reports call for *true airspeed,* 6 for *indicated airspeed,* 3 for *mach number,* and 5 others do not specify which type is to be used. If we ignore these distinctions, which stem largely from differences of opinion about the extent to which raw airspeed information should be processed before presentation to the pilot, we find virtual unanimity. All reports call for some form of airspeed for takeoff, and all but one require it for en route and landing. So, too, with altitude information. If we disregard the distinction between pressure and radar altitude, we find that the tally is 6 of 7 for takeoff, 6 of 6 en route, and 15 of 16 for landing.

There is a third reason for caution in reaching conclusions from the data in Table 2. No distinction for aircraft type has been made in the listings. Only two of the reports (6 and 7) deal with V/STOL aircraft; helicopter requirements are treated scantily (and by inference only) in one or perhaps two reports. For example, we find items such as *yaw* or *lift engine thrust vector angle* listed in only three and two reports respectively. However, these items should not be dismissed without further examination since they occur in all the reports which deal specifically with V/STOL aircraft. Similarly, the mission of the aircraft has not always been given the weight it deserves. Terrain avoidance and weapon delivery requirements are scarcely represented at all in the studies we have selected here; and, for this reason, they will be discussed later in separate sections. Transport, reconnaissance, and trainer aircraft create special informational needs for the pilot because of their specialized missions, and these are not taken up at all in the studies which make up Table 2. Therefore, Table 2 and the subsequent lists we derive from it should not be taken as a complete statement of the information requirements for all aircraft. Rather, we are seeking to establish that information which is the basic and irreducible minimum for aircraft, recognizing that specialization by aircraft type or mission will bring with it additional,peculiar information requirements.

In order to make the list in Table 2 useful for comparison with the content of contemporary E/O displays, it has been necessary to refine it somewhat to eliminate redundancies and items of marginal interest. The items which have been deleted are as follows:

> Yaw angle has been eliminated because we cannot justify it as an information requirement for all aircraft. It is cited as an important item only for V/STOL aircraft, although it may be of importance for helicopters as well. For fixed wing aircraft it seems to be of little significance except insofar as it may be synonymous with crab angle.
>
> Pressure or radar altitude is called out specifically in some reports; others do not distinguish between the two. For convenience, we also prefer the general requirement, altitude, with the understanding that one form or the other may be preferable for certain flight phases or display uses.
>
> True airspeed, indicated airspeed, and mach number are all mentioned in Table 2. For our present purpose the general category, airspeed, will suffice.
>
> Bank has been deleted since it can be considered either a synonym for roll angle or, in the case of command bank, a subtopic under steering. For those reports which use the term bank, we shall count the item under roll or steering, as appropriate.
>
> Heading, pitch, roll and bank commands, and heading error have been merged into the major category, steering.
>
> Aiming point has been deleted because the term is somewhat ambiguous. The information requirement is believed to be more adequately specified by terms such as velocity vector, touchdown point, or target position, as applicable.

In addition to these deletions, we have simplified the requirements lists by dropping the distinction among command, status, and error for individual items. It seems sufficient to indicate what information is required without becoming embroiled in the question of what form in which it is to be presented.

Also in the interest of simplification, we have seen fit to eliminate the categories of power and thrust, airframe control surfaces, and system status information. In the case of system status, we have done so with reluctance. While few analysts have called out this category as a requirement and few contemporary displays actually present this kind of information,

E/O displays offer exceptional possibilities in this regard. The E/O display tends to be an integrated, multiparameter display, and as such it is the focus of pilot attention. This fact, coupled with the capacity of the E/O display to present a variety of alphanumeric characters, suggests that the display has great potential as a medium for presenting caution, warning, and advisory information and as a readout device for system test and check out. We bow to the weight of current opinion and practice, but we also urge that a standardization committee give serious attention to including system status information as a requirement.

Of the information requirements of Table 2 which remain after these deletions and simplifications, the following seem to be of generally accepted importance.

- Pitch angle	- Glideslope
- Roll angle	- Glidepath
- Altitude	- Vertical velocity
- Airspeed	- Range to go
- Steering	- Velocity vector
- Angle of attack	- Fuel quantity
- Heading	- Fuel flow rate

The requirements are listed in approximate rank order on the basis of the number of times specified. Frequency ranges from unanimous or nearly unanimous on the first five items to five of a possible 16 listings for fuel quantity and flow rate.

The information requirements given below were cited less than five times in Table 2.

- Pitch trim	- Ground track
- Turn rate	- Course
- Pull-up (topographic obstacle)	- Groundspeed
- Waveoff (go-around)	- Aircraft position
- Sideslip	- Time to go (to objective)
- Runway heading	- Dangerous weather
- Runway distance	- Carrier position

As we indicated earlier, a simple summation is hardly an ideal method for establishing the importance of a given information item. Pull-up, for example, is listed only twice (as *topographic obstruction*) in Table 2. Nevertheless, pull-up information is vital to pilots who are flying low altitude high speed missions. Also, vertical orientation is not mentioned in any of the studies in Table 2, yet it is of obvious importance. In fairness to the authors of these studies, we suppose that vertical orientation was considered implicit in roll and pitch information, but we would prefer to call it out separately in order to give it the attention it deserves. In addition, it should be noted that hover position, hover groundspeed, and lateral ground velocity received no mention in Table 2. These are information items of importance for helicopters and V/STOL aircraft, and the omission can be attributed to the fixed-wing bias of the studies sampled.

Despite these shortcomings, the data from Table 2 can serve as a rough guide for the evaluation of contemporary E/O displays, which follows in the next section. These information requirements, with the modifications described above, are set forth in Table 3. As in Table 2, Σ denotes the number of reports listing the item as a requirement for each flight phase, and T denotes the total number of reports listing the item as a requirement for any flight phase.

TABLE 3 INFORMATION REQUIREMENTS DERIVED FROM TABLE 2

INFORMATION REQUIREMENTS	TAKEOFF Σ	EN ROUTE Σ	LANDING Σ	TOTAL T
FLIGHT INFORMATION				
Pitch Angle	7	6	16	16
Roll Angle	7	6	16	16
Altitude	6	6	15	15
Airspeed	7	5	15	15
Steering	3	3	11	11
Glideslope	-	-	9	9
Glidepath	-	-	9	9
Angle of Attack	4	1	7	7
Vertical Velocity	5	4	7	7
Velocity Vector[1]	2	2	6	6
Pitch Trim[2]	3	3	4	5
Turn Rate	1	2	2	3
Sideslip	1	2	1	2
Runway Heading	-	-	2	2
Runway Distance	1	-	2	2
Waveoff (Go-around)	-	-	2	2
Pull-up	-	1	1	2
Vertical Orientation[3]	-	-	-	-
Hover Position[3]	-	-	-	-
Hover Groundspeed[3]	-	-	-	-
Lateral Ground Velocity[3]	-	-	-	-
NAVIGATION INFORMATION				
Heading	5	5	8	9
Range to Go	-	2	7	7
Fuel Flow Rate	2	4	3	6
Groundspeed	1	3	4	5
Carrier Position	1	1	2	4
Aircraft Position	1	2	3	3
Ground Track	1	1	2	2
Time to Go	-	1	2	2
Dangerous Weather	-	1	2	2
Course	-	-	1	1

[1] Includes *Aiming Point* requirement of Table 2.
[2] Includes *Best Trim Condition* requirement of Table 2.
[3] Not listed in Table 2; added by authors.

ANALYSIS OF CONTEMPORARY VERTICAL SITUATION DISPLAYS

This section contains an analysis of contemporary vertical situation displays. Our basic purpose in presenting this information is to survey what is being done in the E/O display field and to compare the information content of these displays with the requirements list derived in the preceding section. The E/O display field has evolved so rapidly and so diversely that an overview of this sort seems necessary to help display designers and users take stock of the situation and plot the future course of development. Our review of the research literature has turned up no recent survey of this sort. The study by Baxter and Workman (1962) was an early attempt to do this, but it covered only five displays and by now is considerably out of date. A study by the U. S. Army Human Engineering Laboratories (1967) is more recent but is somewhat limited in scope and does not go to the level of detail which we propose here. There are scores of reports which deal with one display system only, but to review them all and make comparisons is a chore that not all persons interested in this topic can muster the time and endurance to undertake. By summing up this information here we hope to perform a service not only for a standardization committee but for display designers and users in general.

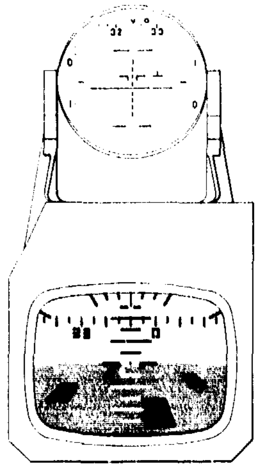
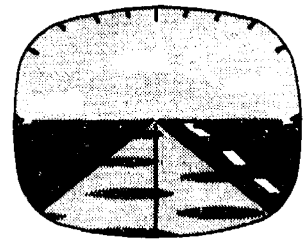
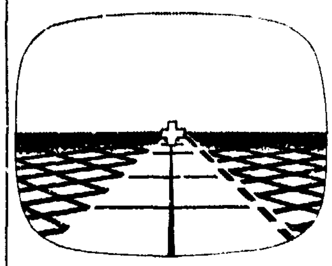
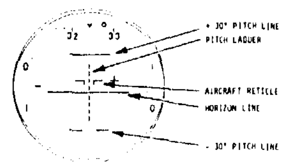
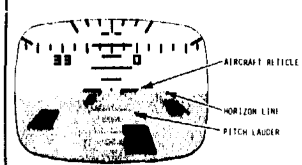
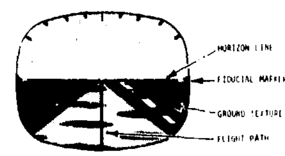
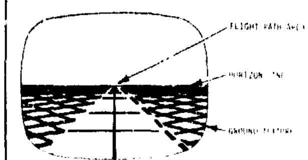
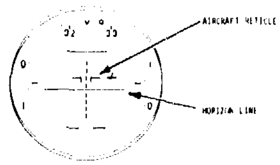
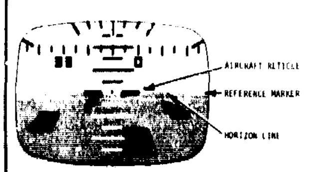
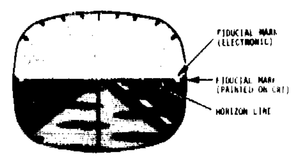
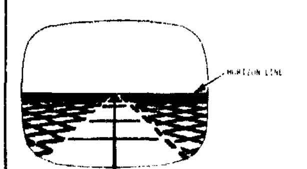
We are using a substantial number of illustrations for two reasons. First, E/O displays are basically pictorial; and the simplest and most direct way of presenting an analysis and comparison is in graphic form. Second, we wish to familiarize the reader with the symbols and format of E/O displays in preparation for the following chapter, which deals with symbology. In compiling this material we have drawn from a variety of source documents which make use of different illustrative techniques. However, in the interests of consistency and ease of comparison, we hav rendered these in a single pictorial style. We apologize for any distortions or inaccuracies that may have thus been introduced. We also wish to point out the inadequacy of any static, printed drawing in doing justice to the actual appearance of E/O displays, which - by nature - are dynamic and luminescent.

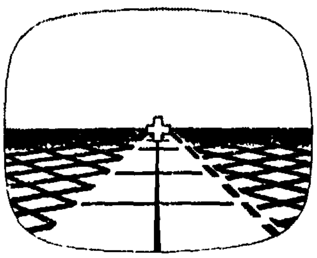
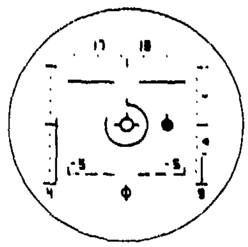
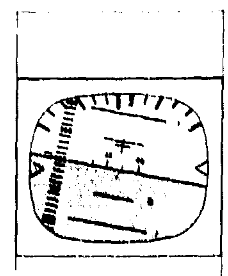
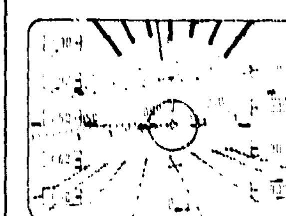
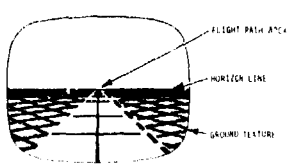
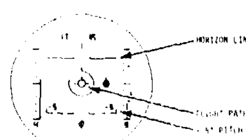
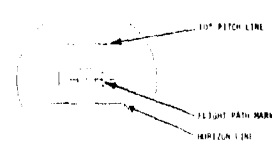
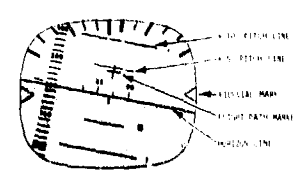
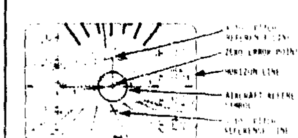
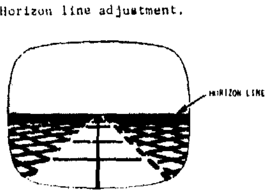
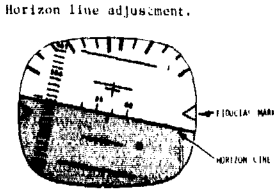
The following tables illustrate eight contemporary vertical situation displays, three of which consist of both head-up and direct view displays, for a total of eleven display formats. The displays are examined for the same three flight phases used in the preceding section: *Takeoff*, *En route*, and *Landing*. Each flight phase is introduced by a full illustration of the display format appropriate for that phase. Following the introductory illustration is a series of smaller, partial illustrations which show how the display presents the information requirements listed in the column on the left margin. Leaders and nomenclature are provided to identify the display elements concerned with each information requirement. The terminology used by the designers of each display has been retained in the illustrations. However, in the interest of developing a common display language, all descriptive commentary is in a standardized terminology of our own devising so that direct comparisons across displays can be made readily.

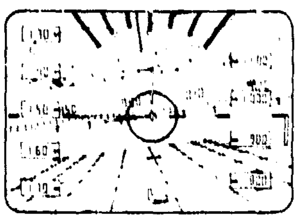
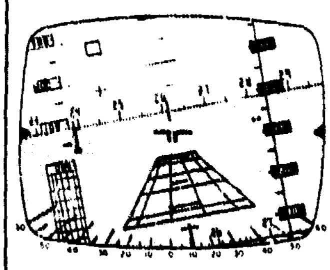
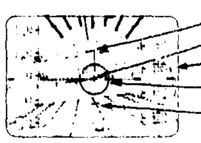
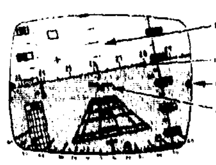
The information requirements listed in these tables are, for the most part, the same as those in Table 3 although the order has been rearranged somewhat in order to achieve a more logical sequence and grouping. It has been necessary to add a few items since some displays contain information not listed as a requirement in Table 3. An illustration in the cell under a given display and opposite a given requirement indicates that the display presents information which satisfies that requirement. An empty cell indicates that the display does not contain the information in question.

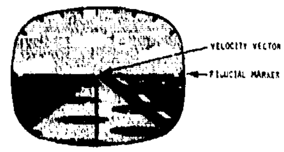
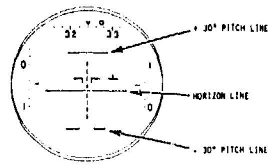
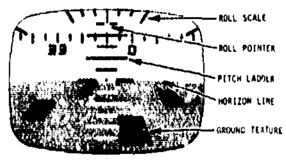
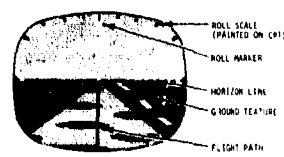
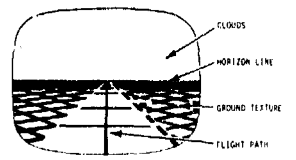
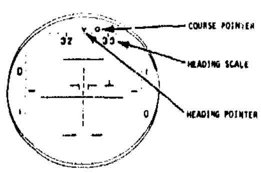
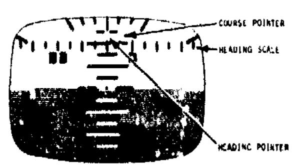
After the series of illustrations for each flight phase, a tabular summary of displays *vs.* information content is given (Tables 5, 7 and 9). These summaries are then combined into a general summary for all flight phases (Table 10) for later comparison with the information requirements set forth in Table 3 of the preceding section.

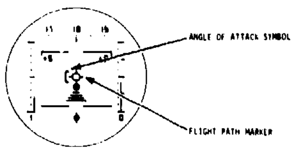
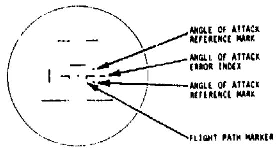
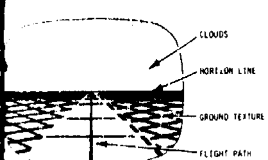
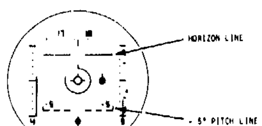
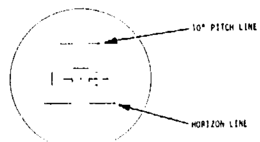
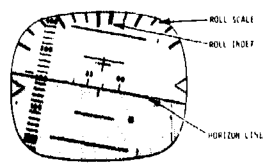
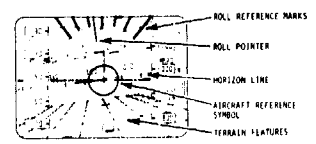
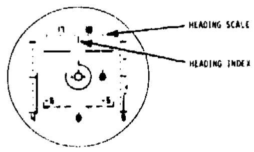
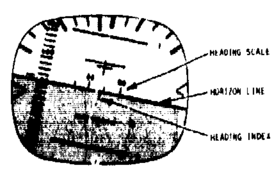
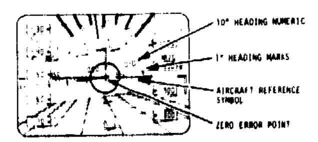
TABLE 4 - ANALYSIS OF VSDs FOR TAKEOFF

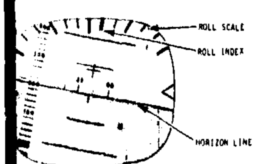
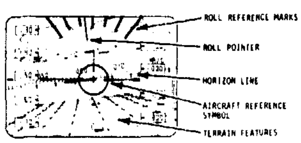
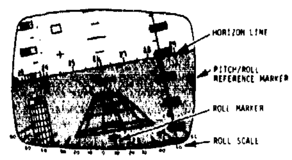
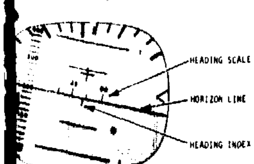
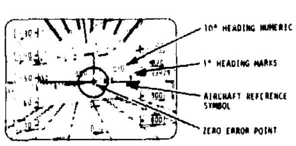
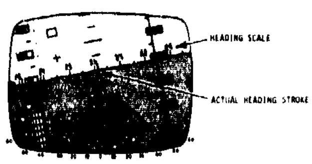
TAKEOFF					
					
VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
PITCH ANGLE	INFORMATION	Pitch attitude.	Pitch attitude.	Pitch attitude.	Pitch attitude.
	SYMBOLOGY				
	DESCRIPTION	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol.	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol.	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at display center.	Horizon line moves vertically as a function of aircraft pitch angle with respect to horizontal reference plane.
	RESPONSE	Inside-out.	Inside-out.	Inside-out.	Inside-out.
	SCALING	Approximately ± 30° vertical coverage. Scale factor 1:6 (compression).	Approximately ± 30° vertical coverage. Scale factor 1:6 (compression).	± 15° vertical coverage. Scale factor 1: 2.5 (compression).	± 9° vertical coverage. Scale factor 1:1.
	REMARKS	Pitch ladder shows 5° increments 0 to ± 20°. Auxillary pitch lines at + 30° (solid line) and - 30° (broken line). Nadir and Zenith not displayed.	Pitch ladder shows 10° major and 5° minor increments 0 to + 30°. Auxillary pitch lines, at ± 30°, ± 60°, and + 90° (not shown), are color coded: black for positive, white for negative.	Auxillary pitch lines, at ± 30°, ± 60° and ± 90° (not shown), are color coded: black for positive, white for negative.	Display center is not marked. No scale provided for quantitative reading of pitch angle.
PITCH TRIM	INFORMATION	Horizon line adjustment.	Horizon line adjustment.	Fiducial marker adjustment.	Horizon line adjustment.
	SYMBOLOGY				
	DESCRIPTION	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.	A manual control permits vertical adjustment of fiducial markers to compensate for differences in pitch attitude for various conditions of level flight.	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.
	RESPONSE				
	SCALING	Range of adjustment ± 20°.	Range of adjustment ± 15°.	Range of adjustment ± 15°.	Range of adjustment ± 6°.
	REMARKS	The local horizon is used for level flight reference.	The local horizon is used for level flight reference.		Detent in manual control used for level flight reference.
	A				B

					
ADI	**AAAIS** FIXED WING **VSD**	**A-7D/E** FIXED WING **HUD**	**ILAAS** FIXED WING **HUD**	**ILAAS** FIXED WING **VSD**	**Norden** ROTARY WING FIXED WING **IEV**
	Pitch attitude. 	Flight path angle. 	Flight path angle. 	Pitch attitude. 	Pitch attitude. 
...es move verti- ...craft pitch ...zontal refer- ...t display cen-	Horizon line moves vertically as a function of aircraft pitch angle with respect to horizontal reference plane.	Horizon and pitch lines move vertically with respect to flight path marker to indicate flight path angle (pitch minus angle of attack). Level flight when horizon and flight path marker coincide.	Horizon and pitch lines move vertically with respect to flight path marker to indicate flight path angle (pitch minus angle of attack). Level flight when horizon and flight path marks coincide.	Horizon line and pitch line move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read from fiducial marks.	Horizon line and pitch lines move ve... tically as a function of aircraft pi... angle with respect to horizontal ref... ence plane. Pitch read at aircraft symbol.
	Inside-out.	Inside-out.	Inside-out.	Inside-out.	Inside-out.
...Scale factor	± 9° vertical coverage. Scale factor 1:1.	Scale factor 1:1.	Scale factor 1:1.	Scale factor about 1:2.5 (compression).	Scale factor 1:5 (compression).
± 30°, ± 60° ...color coded: ...for negative.	Display center is not marked. No scale provided for quantitative reading of pitch angle.	Auxiliary reference lines at + 5°, + 10°, and thereafter at 5° intervals to ± 90°. Pitch angle not displayed. Flight path marker is velocity vector terminus.	Pitch scale centers on unmarked display boresight but is read at flight path marker. Pitch lines at ± 10°, ± 30°, ± 50° and ± 70°. Pitch angle not displayed. Flight path marker = velocity vector.	Pitch scale has ± 10°, ± 30°, ± 50° and ± 70° marked with 1, 3, 5 and 7 respectively; nadir, - 90°, is an open cross; zenith, + 90°, a closed cross that resembles flight director command symbol.	Pitch ladder shows ± 10°.
t. FIDUCIAL MARK (ELECTRONIC) FIDUCIAL MARK (PAINTED ON CRT) HORIZON LINE	Horizon line adjustment. 			Horizon line adjustment. 	
...vertical ad- ...ers to compen- ...ch attitude ...level flight.	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.			A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.	
°.	Range of adjustment ± 6°.			Range of adjustment + 10° to -20°.	
	Detent in manual control used for level flight reference. B			The local horizon is used for level flight reference.	

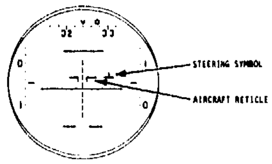
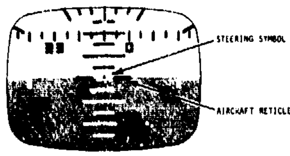
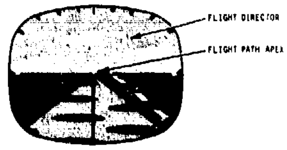
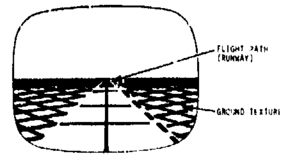
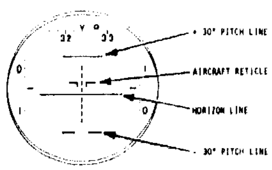
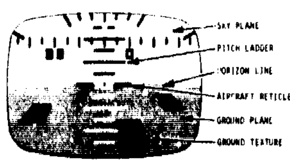
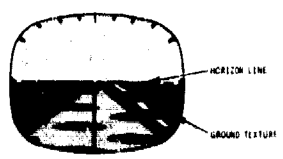
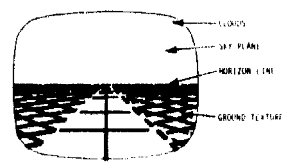
FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
			All Weather VSTOL display is not shown in the takeoff phase.
 ...pitch line move verti-... of aircraft pitch ... to horizontal refer-... read from fiducial ...ut 1:2.5 (compression). ... ± 10°, ± 30°, ± 50° and ... 1, 3, 5 and 7 respec-... 90°, is an open cross; ... closed cross that re-... vector command symbol.	Pitch attitude.  Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol. Inside-out. Scale factor 1:5 (compression). Pitch ladder shows ± 10°.	Pitch attitude.  Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read from pitch and roll reference marks. Inside-out. Display represents ± 27° of pitch. Scale factor 1:5 (compression). Pitch scale has ± 5° and ± 10° increments continuously through range.	
...ment.  ... permits vertical ad-... horizon line to compen-... ences in pitch attitude ... itions of level flight. ...ment + 10° to -20°. ...on is used for level ...e.			

VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD	A-7[D]
ANGLE OF ATTACK	INFORMATION			Angle of attack.		Status a
	SYMBOLOGY					
	DESCRIPTION			Angle of attack shown by vertical separation of velocity vector symbol and imaginary line between fiducial markers.		AOA symb flight p it indic
	RESPONSE			Inside-out, status.		Status,
	SCALING			Scale factor 1:2.5 (compression).		Length o
	REMARKS					Center o inal val blanked units.
ROLL ANGLE	INFORMATION	Roll attitude.	Roll attitude.	Roll attitude.	Roll attitude.	Roll att
	SYMBOLOGY					
	DESCRIPTION	Horizon line and pitch lines rotate to indicate roll.	Horizon line, pitch lines, and ground features rotate to indicate roll. Quantitative information provided by roll pointer and reference marks.	Horizon line, pitch lines, sky and ground features, and flight path rotate to indicate roll. Quantitative information provided by roll pointer and reference marks.	Horizon line, flight path, and sky and ground features rotate to indicate roll.	Horizon indicat
	RESPONSE	Inside-out, status.	Inside-out, status.	Inside-out, status.	Inside-out, Status.	Inside-
	SCALING	Scale factor 1:1.	Scale factor 1:1.	Scale factor 1:1.	Scale factor 1:1.	Scale f
	REMARKS	Peripheral scales are aircraft-stabilized (do not roll). No scale marks for quantitative reading of roll angle.	Peripheral scales are earth-stabilized (roll with horizon). Roll reference marks at ± 10°, ± 20°, ± 30° and ± 60°.	Roll reference marks at 15° increments 0 to ± 60°.	No scale marks for reading of roll angle.	Peripher (do not titative
HEADING	INFORMATION	Magnetic heading and course.	Magnetic heading and course.			Magneti
	SYMBOLOGY					
	DESCRIPTION	Heading tape moves to indicate actual heading. Read at fixed index. Course pointer moves along scale to indicate actual course.	Heading tape moves to indicate actual heading. Read at roll pointer. Course pointer moves along scale to indicate actual course.			Heading cate act heading
	RESPONSE	Inside-out, status.	Inside-out, status.			Inside-
	SCALING	Coverage about 16°. Scale factor 1:3.2 (compression).	Coverage 75°. Scale factor 1:6 (compression).			Scale f
	REMARKS	Scale marks at 2° increments with numerals every 10°. Manually selectable on or off.	Scale marks at 10° major and 5° minor with numerals every 30°. Heading scale is black with steering commands present and white without steering when scale is primary reference. Manual on/off.			Heading mode.

AAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS
	Status angle of attack  AOA symbol is fixed. Position of flight path marker in relation to it indicates actual AOA. Status, fly-from. Length of bracket = 2 units AOA. Center of AOA symbol represents nominal value of 17.5 units. AOA symbol blanked whenever AOA less than 12 units.	Deviation from command angle of attack.  AOA error index moves vertically with reference to the right wing of the flight path marker to indicate AOA error. AOA reference marks are fixed with respect to the flight path marker. Fly-from. A high symbol indicates a + AOA error and is a command to decrease. Not specified.			
...ll attitude.  ...izon line, flight path, and sky and ...ound features rotate to indicate ...ll. ...side-out, Status. ...ale factor 1:1. ... scale marks for reading of roll ...	Roll attitude.  Horizon line and pitch lines rotate to indicate roll. Inside-out, status. Scale factor 1:1. Peripheral scales are aircraft stabilized (do not roll). No scale marks for quantitative reading of roll angles.	Roll attitude.  Horizon line and pitch lines rotate to indicate roll. Inside-out, status. Scale factor 1:1. Though not specified, it is assumed that horizon and pitch lines rotate about the unmarked display center (boresight).	Roll attitude.  Horizon line and pitch lines rotate to indicate roll. Quantitative information provided by roll pointer and reference marks. Inside-out, status. Scale factor 1:1. Peripheral scales are earth stabilized (roll with horizon). Reference marks at 10° intervals, 0° to 60°.	Roll attitude.  Horizon line, pitch lines, and sky and ground features rotate to indicate roll. Quantitative information provided by roll pointer and reference marks. Inside-out, status. Scale factor 1:1. Peripheral scales are aircraft stabilized (do not roll). Reference marks at 0°, ± 10°, ± 20°, ± 30° and ± 60° roll angles.	Roll attitu...  Horizon lin... indicate ro... Inside-out,... Scale fact... Peripheral ... (roll with ... in 5° minor...
	Magnetic heading.  Heading tape moves horizontally to indicate actual heading. Read at the fixed heading index. Inside-out, status. Scale factor 1:4.4. Heading not displayed in decluttered mode. B		Magnetic heading.  Heading tape on horizon moves to indicate actual heading. Read at fixed heading index marker. Inside-out, status. Scale factor approximately 1:2.5 (compression). Scale marks in 5° increments with numerals every 10°. Heading scale also appears on ± 30° pitch lines.	Magnetic heading.  Heading tape moves along horizon to indicate actual heading. Read at zero error point (center of aircraft reference symbol). Inside-out, status. 50° coverage. Scale factor 1:4 (compression). Scale marks at 1° increments, with numerals every 10°. Changes in heading also indicated by movement and changes in orientation of ground texture.	Magnetic He...  Heading ta... cate actua... section of... Inside-out... Scale fact... Scale mark... erals ever... appears on...

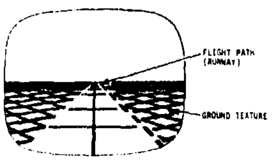
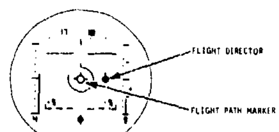
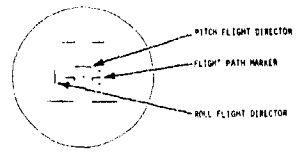
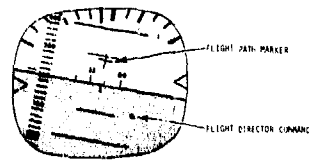
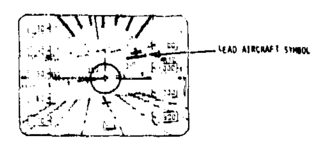
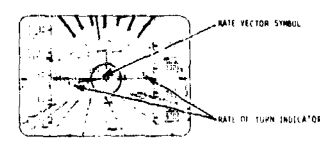
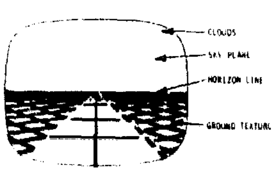
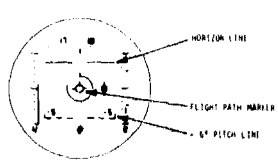
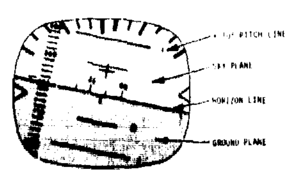
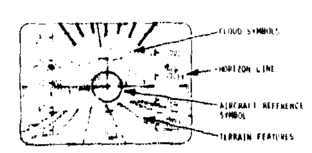
LAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
l attitude.  i..on line and pitch lines rotate to i..ate roll. Quantitative information vi..d by roll pointer and reference k... I.. ..ut, status. le factor 1:1. iphe..al scales are earth stabilized ll with horizon). Reference marks at intervals, 0° to 60°.	Roll attitude.  Horizon line, pitch lines, and sky and ground features rotate to indicate roll. Quantitative information provided by roll pointer and reference marks. Inside-out, status. Scale factor 1:1. Peripheral scales are aircraft stabilized (do not roll). Reference marks at 0°, ± 10°, ± 20°, ± 30° and ± 60° roll angles.	Roll attitude.  Horizon line and pitch lines rotate to indicate roll. Inside-out, status. Scale factor 1:1. Peripheral scales are earth stabilized (roll with horizon). Roll scale marked in 5° minor and 10° major increments.	
netic heading.  ing tape on horizon moves to indi- actual heading. Read at fixed ing index marker. ..e-out, status. e factor approximately 1:2.5 (com- sion). e marks in 5° increments with numer- every 10° Heading scale also ap- on ± 30° pitch lines.	Magnetic heading.  Heading tape moves along horizon to indicate actual heading. Read at zero error point (center of aircraft reference symbol). Inside-out, status. 50° coverage. Scale factor 1:4 (compression). Scale marks at 1° increments, with numerals every 10°. Changes in heading also indicated by movement and changes in orientation of ground texture.	Magnetic Heading.  Heading tape on horizon moves to indicate actual heading. Read at intersection of actual heading stroke. Inside-out, status. Scale factor 1:5. Scale marks in 5° increments with numerals every 10°. Heading scale also appears on ± 30° pitch lines.	Preceding page blank

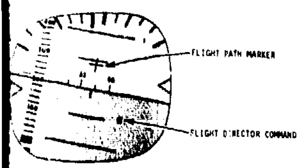
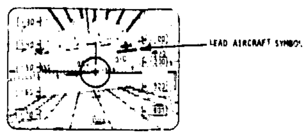
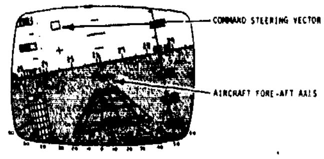
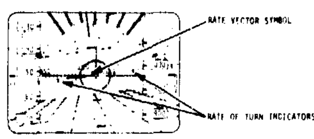
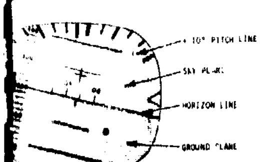
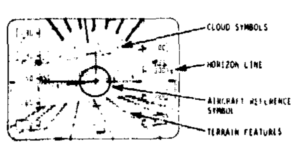
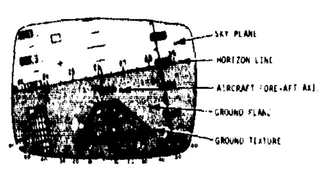
C

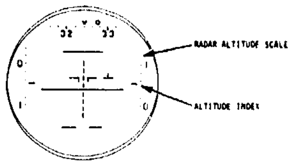
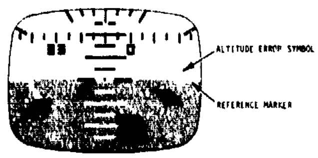
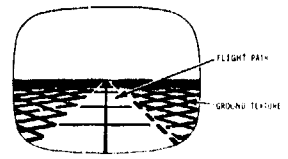
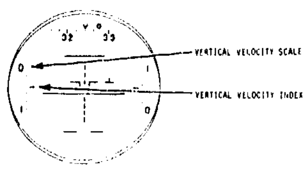
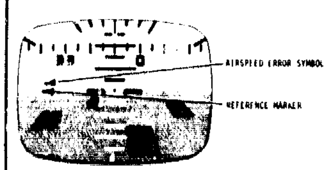
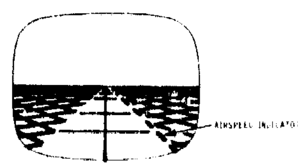
VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
STEERING	INFORMATION	Command heading.	Command Heading.	Command pitch and roll.	Deviation from runway heading.
	SYMBOLOGY				
	DESCRIPTION	Symbol displaced from null position at aircraft reticle to indicate required changes in heading.	Symbol displaced from null position at aircraft reticle to indicate required changes in heading.	Pathway and flight director symbols displaced from null position at display center to indicate required changes in heading and/or pitch.	Pathway locked at runway heading. Rotation and lateral translation of pathway indicate deviation from runway center line.
	RESPONSE	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command.
	SCALING	Scale factor 1:6 (compression).	Scale factor 1:6 (compression). 1 inch = 11°.	Scale factor 1: 3.3 (compression) horizontally and vertically.	Total coverage approximately ± 11°. Scale factor 1:1.
	REMARKS	Simple displacement commands. Symbol limits at ± 25° of heading error. Symbol can also indicate pitch commands given such inputs.	Simple displacement commands. Symbol limits at ± 25° of heading error. Symbol can also indicate pitch commands given such inputs.	Steering commands based on displacement and rate— roll sum and pitch sum steering. Flight path apex shows direction and magnitude of required change. Flight director shows rate and error summed.	Changes in heading are also indicated by lateral movement of ground texture elements.
TURN RATE	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS	Qualitative indication of turn rate provided by rate of movement of magnetic heading scale.	Qualitative indication of turn rate provided by rate of lateral movement of magnetic heading scale and ground texture.	Qualitative indication of turn rate provided by rate of lateral movement of ground texture.	Qualitative indication of turn rate provided by rate of lateral movement of ground texture.
VERTICAL ORIENTATION	INFORMATION	Vertical orientation.	Vertical orientation.	Vertical orientation.	Vertical orientation.
	SYMBOLOGY				
	DESCRIPTION	+ 30° pitch line is solid. - 30° pitch line is broken.	Sky and ground are differentiated by gray tone shading and by ground texture elements. Tail of steering symbol always points up; roll pointer points down.	Sky and ground are differentiated by grey tone shading, clouds, ground texture elements, and pitch line coding.	Sky and ground are differentiated by ground texture grid and clouds.
	RESPONSE	Inside-out, status.	Inside-out, status.	Inside-out, status.	Inside-out, status.
	SCALING	N.A.	N.A.	N.A.	N.A.
	REMARKS	Vertical orientation cues not shown on display in pitch attitudes beyond ± 50°.	Major pitch lines are color coded: black for positive; white for negative pitch angles. Perspective of ground texture elements indicates direction of nearest horizon in nose-down attitude.	Perspective of ground texture elements indicates direction of nearest horizon in nose-down attitude.	Perspective of ground texture grid indicates direction of nearest horizon in nose-down attitude.

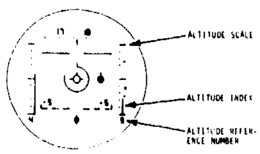
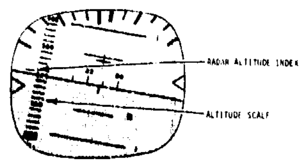
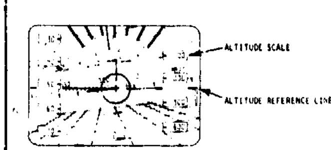
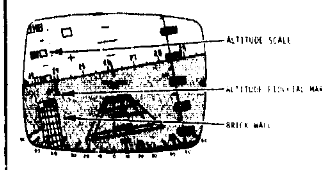
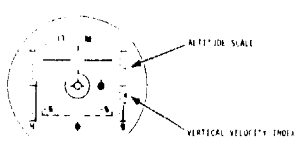
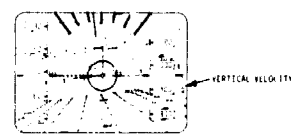
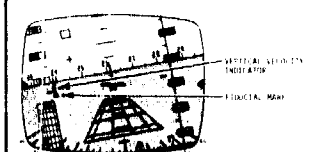
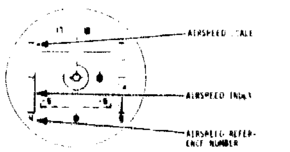
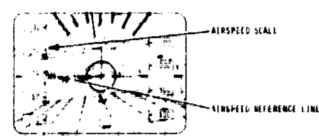
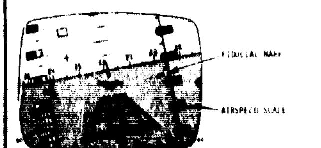
A

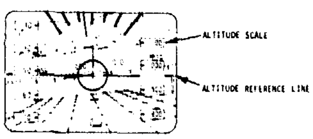
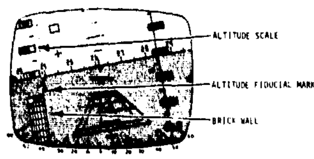
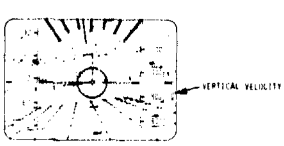
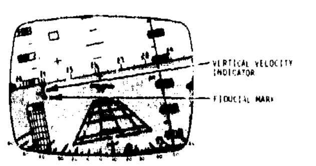
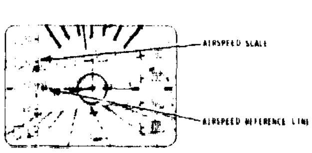
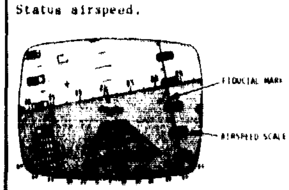
B

AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHA
Deviation from runway heading.	Command heading and pitch.	Command heading and pitch.	Command heading and pitch.	Command heading, pitch and roll.	Commanc
					
Pathway locked at runway heading. Rotation and lateral translation of pathway indicate deviation from runway center line.	Flight director symbol displaced from null position at flight path marker to indicate required changes in heading.	Two flight director components are driven individually from null position at flight path marker to indicate required changes in heading and/or pitch.	Two flight director components are driven individually from null position at flight path marker to indicate required changes in heading and/or pitch.	Symbol displaced from null position at display center to indicate required changes in heading, pitch, and/or roll. Can also rotate about its axis at any point to indicate bank command.	Comman from n symbol headir
Fly-to, command.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-tc
Total coverage approximately ± 11°. Scale factor 1:1.	Not specified.	Not specified.	Not specified.	Not specified.	Not s
Changes in heading are also indicated by lateral movement of ground texture elements.		"Roll" flight director commands heading change rather than roll. Both flight director components are combined into a cross (flight director symbol) when simultaneous heading and pitch commanded.	The flight director command consists of a pitch flight director symbol and a "roll" flight director symbol. The latter commands changes in heading, not roll.	Normally a zero-reader symbol, but can also be used as a predictor (future status) or rate command symbol. Can also be varied in size or shape to provide additional command cues.	In ve vecto the r be a or in
				Rates of turn.	
					
				A "rate vector" symbol, originating from center of horizon, extends to left or right by an amount proportional to rate of turn. Reference marks designate 1-, 2-, & 4-min turns.	
				Status. Markings move to the right for a right turn.	
				1, 2, and 4 minute turn rates.	
Qualitative indication of turn rate provided by rate of lateral movement of ground texture.	Qualitative indication of turn rate provided by rate of movement of heading scale.		Qualitative indication of turn rate provided by rate of movement of heading scale.	Rate of turn markers move independently of heading scale.	Qual prov of g
Vertical orientation.	Vertical orientation.		Vertical orientation.	Vertical orientation.	Vert
					
Sky and ground are differentiated by ground texture grid and clouds.	Minus pitch lines are dashed and marked with negative numerals; plus pitch lines are solid and marked with numerals.		Sky and ground texture are differentiated by gray tone shading. Pitch lines are marked with numerics. Zenith and nadir are a closed and open cross respectively.	Sky and ground texture are differentiated by gray tone shading, cloud symbols and a grid pattern.	Sky ate ele
Inside-out, status.	Inside-out, status.		Inside-out, status.	Inside-out, status.	Ins
N.A.	N.A.		N.A.	N.A.	N.A
Perspective of ground texture grid indicates direction of nearest horizon in nose-down attitude. B	All pitch scale numerics are earth stabilized. Hence, if they appear upside down, they indicate an inverted attitude.		All numerals are earth stabilized. Hence, if they appear upside down, they indicate an inverted attitude.	All numerics are earth stabilized. If they appear upside down, they indicate an inverted attitude. Ground texture perspective indicates location of nearest horizon in nose-down attitude.	Al (re cr no

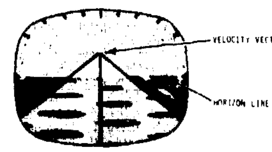
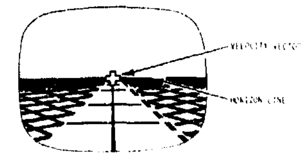
LAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL V/STOL HUD/VSD
...mmand heading and pitch.  ...e flight director components are dri-...n individually from null position at ...ight path marker to indicate requir-...changes in heading and/or pitch. ...-to, command, compensatory tracking. ...t specified. ...e flight director command consists ...a pitch flight director symbol and ..."roll" flight director symbol. The ...ter commands changes in heading, ...roll.	Command heading, pitch and roll.  Symbol displaced from null position at display center to indicate requir-ed changes in heading, pitch, and/or roll. Can also rotate about its axis at any point to indicate bank command. Fly-to, command, compensatory tracking. Not specified. Normally a zero-reader symbol, but can also be used as a predictor (future sta-tus) or rate command symbol. Can also be varied in size or shape to provide additional command cues.	Command heading and altitude.  Command steering vector symbol displaced from null position at aircraft reference symbol to indicate required changes in heading and/or altitude. Fly-to, command, compensatory tracking. Not specified. In vertical direction, command steering vector acts as an altitude command; the response to symbol displacement may be a change in aircraft pitch attitude or in lift factor (rotor blade pitch).	
...itative indication of turn rate ...ided by rate of movement of head-...scale.	Rates of turn.  A "rate vector" symbol, originating from center of horizon, extends to left or right by an amount propor-tional to rate of turn. Reference marks designate 1-, 2-, & 4-min turns. Status. Markings move to the right for a right turn. 1, 2, and 4 minute turn rates. Rate of turn markers move indepen-dently of heading scale.	Qualitative indication of turn rate provided by rate of lateral movement of ground texture grid.	
...ical orientation.  ...d ground texture are differentiat-...gray tone shading. Pitch lines ...marked with numerics. Zenith and ...are a closed and open cross re-...tively. ...out, status. ...merals are earth stabilized. ..., if they appear upside down, they ...ate an inverted attitude.	Vertical orientation.  Sky and ground texture are differen-tiated by grey tone shading, cloud symbols and a grid pattern. Inside-out, status. N.A. All numerics are earth stabilized. If they appear upside down, they indi-cate an inverted attitude. Ground tex-ture perspective indicates location of nearest horizon in nose-down attitude.	Vertical orientation.  Sky and ground texture are differenti-ated by gray tone shading and ground elements. Inside-out, status. N.A. All numerics are earth stabilized. Ground texture grid perspective indi-cates location of nearest horizon in nose-down attitude.	Preceding page blank

	VSD DISPLAYS	F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD	A
ALTITUDE	INFORMATION	Radar altitude.	Command altitude (barometric).		Command altitude.	Stat
	SYMBOLOGY					
	DESCRIPTION	Fixed scale and moving pointer indicate radar altitude.	Error symbol moves vertically from fixed reference mark to indicate deviation from command altitude. At null position gap in symbol is centered on reference mark.		Size and pattern of ground texture elements vary with status altitude. Angle formed by pathway apex varies as function of deviation from command altitude.	Alti indi the scal
	RESPONSE	Status, pointer moves up for increased altitude.	Fly-to, command.		Pilot uses pathway as altitude cue as he would runway in contact flight.	Stat
	SCALING	Scale factor 1° = 200 ft.	Scale factor 1 inch equals 800 ft altitude error.		White ground lines on black: 0-100 ft & over 1000 ft; black on white: 100-1000.	Not
	REMARKS	Scale divided into 200 ft. increments 0 to 1400 ft. with numerals at 0 and 1000 ft.	Manually selectable .. or off. Altitude also read in nearest 100 ft. on counter above DVI.		Runway altitude is reference altitude for take-off. Transition from takeoff to enroute altitude made by manually changing command altitude selection.	10 cre Sal pla not
VERTICAL VELOCITY	INFORMATION	Rate of ascent/descent.				Rate
	SYMBOLOGY					
	DESCRIPTION	Fixed scale and moving pointer indicate vertical velocity.				Fix ver
	RESPONSE	Status. Pointer moves above zero for ascent, below zero for descent.				Stat
	SCALING	Scale factor 1° = 200 fpm.				Not
	REMARKS	Scale divided into 200 fpm increments with numerals at 0 and - 1000 fpm. Range + 400 fpm to - 1000 fpm.			No quantitative indication of vertical velocity; however, pathway displacement programmed for both altitude error and command rate of change.	Air vel
AIR SPEED	INFORMATION		Command airspeed.		Command airspeed.	Stat
	SYMBOLOGY					
	DESCRIPTION		Error symbol moves vertically from fixed reference mark to indicate deviation from command airspeed. At null position gap in symbol is centered on reference mark.		Movement of dashed lines on right of flight path indicates deviation from command airspeed.	Aira inde tati of t scal
	RESPONSE		Command. Fly-from (upward symbol displacement commands decrease in airspeed.		Command. Fly-to.	Stat
	SCALING		Scale factor 1 inch equals 80 kts		Relation of rate of movement to magnitude of error not specified.	Not
	REMARKS	A	Airspeed also read to nearest 10 kts on a counter above DVI.		When actual airspeed equals command airspeed, the dashed lines are stationary. When actual greater than command, lines move downward, and vice versa.	Scal ever knot spee

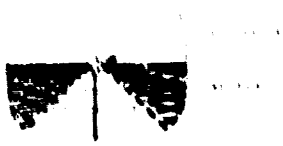
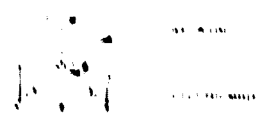
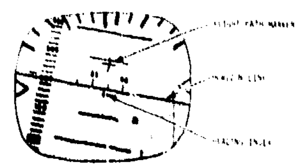
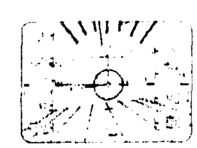
VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI
	Status and command altitude. 		Status altitude. 	Altitude. 	Status radar altitude. 
...ure ele-. Angle ... func- altitude.	Altitude scale fixed. Thermometer type indexer moves on scale. The number at the scale base (*e.g.* 9) indicates the scale begins at 9000 ft.		Altitude tape moves against fixed reference line to provide quantitative altitude information.	Altitude tape moves against fixed reference line to provide quantitative altitude information.	Movable vertical tape read against fixed fiducial marker indicates radar altitude.
...as he	Status.		Status. Tape moves downward for increase in altitude.	Status. Tape moves downward for increased altitude.	Status. Tape moves downward for increased altitude.
... ft & ...1600.	Not specified.		Scale factor 100 ft/in.	1 raster line equals 1 foot altitude or approx. 60 feet per inch.	
...itude for ...to ...ly chang-	1000 ft scale structure has 100 ft increments with major marks every 250 ft. Radar or barometric altitude is displayed depending on mode. Max range not specified.		Scale has 20 feet increments with numerics every 100 ft to 5000 ft. There are 400 ft of scale in view at any one time. "Brick wall" appears at 0 ft. Scale is earth stabilized (rolls with horizon).	Scale has 100 ft increments. Barometric or radar altitude not specified (either may be used).	400 ft of scale in view at any one time. 50 ft increments; numerics every 100 ft. Scale not displayed above 5000 ft. "Brick wall" appears at 0 ft. Scale rolls with raster (earth stabilized).
	Rate of ascent/descent. 			Rate of ascent/descent. 	Rate of ascent/descent. 
	Fixed scale and moving pointer indicate vertical velocity.			Vertical velocity represented by bar extending from altitude reference mark. Length of bar proportional to vertical velocity.	Vertical velocity displayed by bar emanating from altitude fiducial marker. Length of bar proportional to vertical velocity.
	Status.			Status. Bar extends upward for ascent; downward for descent.	Status. Bar extends upward for ascent; downward for descent.
	Not specified.			Not specified.	Scale factor 1 in = 200 fpm.
...ertical ...lacement ...error	Altitude scale also serves as vertical velocity scale.				Index marks at 100 fpm increments. Range ± 400 fpm.
	Status airspeed. 			Status airspeed. 	Status airspeed. 
...ht of ...from	Airspeed scale fixed. Thermometer type indexer moves on scale to provide quantitative airspeed. The number at the base of the scale (*e.g.* 4) indicates the scale begins at 400 kts.			Moving vertical tape read against fixed reference line indicates status airspeed.	Movable vertical tape read against fixed fiducial marker indicates airspeed.
	Status.			Status. Tape moves upward with increased airspeed.	Status. Tape moves downward for increase in airspeed.
...magni-	Not specified.			Not specified.	Scale factor 10 kts/in.
...and ai- ...ionary. ..., lines	Scale has 10 knot increments with dots every 10 knots and major marks every 50 knots. Max. range not specified. Airspeed not displayed in decluttered mode.	B		Note airspeed and altitude tapes move in opposite direction for increasing values. Numerals at 10 kt intervals from - 50 to + 570 kts.	5 kt scale increments with numerals every 10 kts. 40 kts of scale in view at any given time. Negative airspeed indicated by minus sign. (See also ground speed).

VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
ALTITUDE INDEX SCALE ixed refer- tive alti- for in- wi h numer- There are ny one time. . Scale is horizon).	Altitude.  Altitude tape moves against fixed reference line to provide quantitative altitude information. Status. Tape moves downward for increased altitude. 1 raster line equals 1 foot altitude or approx. 60 feet per inch. Scale has 100 ft increments. Barometric or radar altitude not specifird (either may be used).	Status radar altitude.  Movable vertical tape read against fixed fiducial marker indicates radar altitude. Status. Tape moves downward for increased altitude. 400 ft of scale in view at any one time; 50 ft increments; numerics every 100 ft. Scale not displayed above 5000 ft. "Brick wall" appears at 0 ft. Scale rolls with raster (earth stabilized).	
	Rate of ascent/descent.  Vertical velocity represented by bar extending from altitude reference mark. Length of bar proportional to vertical velocity. Status. Bar extends upward for ascent; downward for descent. Not specified.	Rate of ascent/descent.  Vertical velocity displ.yed by bar emanating from altitude fiducial marker. Length of bar proportional to vertical velocity. Status. Bar extends upward for ascent; downward for descent. Scale factor 1 in = 200 fpm. Index marks at 100 fpm incremen's Range ± 400 fpm.	
	Status airspeed.  Moving vertical tape read against fixed reference line indicates status airspeed. Status. Tape moves upward with increased airspeed. Not specified. Note airspeed and altitude tape. move in opposite direction for increasing values. Numerals at 10 kt intervals from - 50 to + 570 kts.	Status airspeed.  Movable vertical tape read against fixed fiducial marker indicates airspeed. Status. Tape moves downward for increase in airspeed. Scale factor 10 kts/in. 5 kt scale increments with numerals every 10 kts. 40 kts of scale in view at any given time. Negative airspeed indicated by minus sign. (See also ground speed).	Preceding page blank

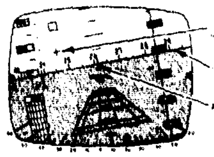
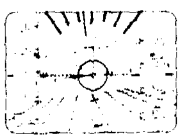
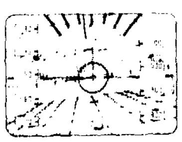
 C

VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
VELOCITY VECTOR	INFORMATION			Actual flight path through the airmass.	Actual flight path through the airmass.
	SYMBOLOGY				
	DESCRIPTION			The position of the velocity vector symbol with respect to the horizon line and/or the flight path apex denotes the actual flight path or velocity vector of the aircraft.	The position of the velocity vector symbol with respect to the horizon line and/or the flight path apex denotes the actual flight path or velocity vector of the aircraft.
	RESPONSE			Fly-from (velocity vector flown from present position to desired position).	Fly-from (velocity vector flown from present position to desired position).
	SCALING			Vertical scale factor 1:2.5; horizontal scale factor 1:3.3 (both compression).	Scale factor 1:1.
	REMARKS			The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.	The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.
RUNWAY HEADING ERROR	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS				See steering.
RUNWAY DISTANCE	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS				

A

	AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IH[illegible]
	[illegible] flight path through the airmass.  [illegible] [illegible] [illegible] [illegible]	Actual flight path through the airmass.  The position of the flight path marker with respect to the horizon line denotes the actual flight path or velocity vector of the aircraft. Fly-t[illegible] flight path [illegible] flown [illegible] present position [illegible] horizon line). [illegible] This mechanization, the flight path [illegible] the direction of the velocity vector with respect to the real world.	Actual flight path through the airmass  Flight path marker denotes actual flight path or aircraft velocity vector. Drift is its lateral displacement from center. The horizon line position in relation to it indicates aircraft flight path. Fly-to (flight path marker flown to moving horizon line). Not specified. In this mechanization, the flight path is represented by the relation between the flight path marker and horizon symbols. Neither symbol position displayed is <u>directly</u> related to the real world.	Actual flight path through the airmass.  The position of the flight path marker with respect to the horizon line and heading index denotes the actual flight path or velocity vector of the aircraft. Fly-from (flight path marker flown from present position to desired position). Not specified. The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.		Actua[illegible]  Posit[illegible] relat[illegible] head[illegible] of [illegible] Fly-[illegible] Not [illegible] Dur[illegible] Sel[illegible] symb[illegible]
	[illegible]				Deviation from runway heading.  Not specified. Not specified. Not specified. Reference documents indicate the display of runway heading error for the takeoff mode but no symbology is depicted.	
					Distance along the runway.  Not specified. Not specified. Not specified. Reference documents indicate the display of runway distance for the takeoff mode but no symbology is depicted.	

B

VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
the airmass. path marker line and actual flight the aircraft. flown from position). point of it the aircraft		Actual flight path through the airmass.  Position of velocity vector symbol in relation to horizon line and actual heading stroke indicates actual path of aircraft through the airmass. Fly-from. Not specified. During vertical ascent or descent, symbol will be off display. Dynamics of symbol during hover not specified.	
	Deviation from runway heading.  Not specified. Not specified. Not specified. Reference documents indicate the display of runway heading error for the takeoff mode but no symbology is depicted.		
	Distance along the runway.  Not specified. Not specified. Not specified. Reference documents indicate the display of runway distance for the takeoff mode but no symbology is depicted.		

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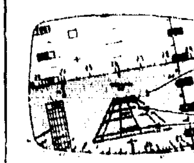
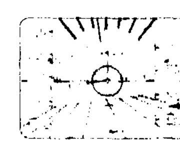
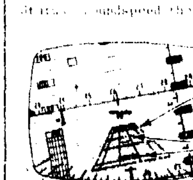
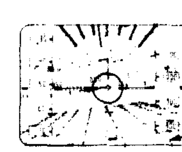
C

VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD	A
GROUNDSPEED	INFORMATION					
	SYMBOLOGY					
	DESCRIPTION					
	RESPONSE					
	SCALING					
	REMARKS					
HOVER GROUNDSPEED	INFORMATION					
	SYMBOLOGY					
	DESCRIPTION					
	RESPONSE					
	SCALING					
	REMARKS					
LATERAL GROUND VELOCITY	INFORMATION					
	SYMBOLOGY					
	DESCRIPTION					
	RESPONSE					
	SCALING					
	REMARKS	A				

FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WIN
					Error from command groun  For forward speeds of horizontal elements of grid move up and down cate difference between actual ground speed. Fly-to. Elements move speed greater than Element movement is pr ror, Because of perspective, to move toward or away
				Status groundspeed (hover).  Horizontal elements of ground texture grid move down the display at velocity proportionate to groundspeed. Status indicator, qualitative. Not specified. For rotary wing aircraft, ground texture grid moves up or down. At zero groundspeed, grid is stationary.	Status groundspeed  For ground speeds less horizontal elements of grid move down the displ proportionate to actual Status indicator, quali Maximum velocity of hori 2.5 in/sec = 30 kts. At zero groundspeed, the grid is stationary. Bec spective, elements appe ward or away from observ
	B			Lateral ground velocity.  Radial elements of ground texture grid move laterally to denote lateral velocity. At zero lateral velocity, elements are stationary. Status indicator, qualitative. Elements move opposite to motion of aircraft. Not specified.	Cross heading velocity.  Radial elements of groun move laterally to denot city. At zero lateral ments are stationary. Status indicator, quali move opposite to motion Element speed proportio velocity; max speed 2.5 Preceding

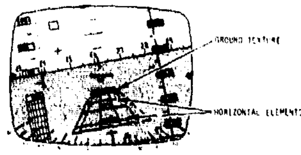
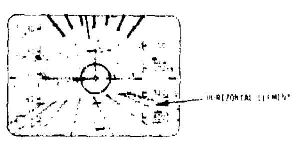
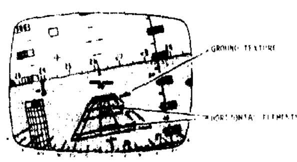
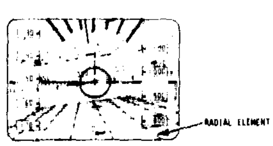
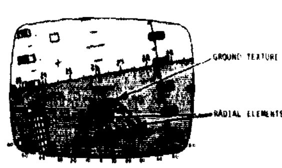
FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
		Error from command groundspeed.  For forward speeds of 30 kts or more, horizontal elements of ground texture grid move up and down display to indicate difference between command and actual ground speed. Fly-to. Elements move down to indicate speed greater than command; vice versa. Element movement is proportionate to error, reaching max vel. at 30 kts error. Because of perspective, elements appear to move toward or away from observer.	
	Status groundspeed (hover).  Horizontal elements of ground texture grid move down the display at velocity proportionate to groundspeed. Status indicator, qualitative. Not specified. For rotary wing aircraft, ground texture grid moves up or down. At zero groundspeed, grid is stationary.	Status groundspeed (hover).  For ground speeds less than 30 kts, horizontal elements of ground texture grid move down the display at velocity proportionate to actual ground speed Status indicator. Qualitative. Maximum velocity of horizontal elements 2.5 in/sec = 30 kts. At zero groundspeed, the ground texture grid is stationary. Because of perspective, elements appear to move toward or away from observer.	
	Lateral ground velocity.  Radial elements of ground texture grid move laterally to denote lateral velocity. At zero lateral velocity, elements are stationary. Status indicator, qualitative. Elements move opposite to motion of aircraft. Not specified.	Cross heading velocity.  Radial elements of ground texture grid move laterally to denote lateral velocity. At zero lateral velocity, elements are stationary. Status indicator, qualitative. Elements move opposite to motion of aircraft. Element speed proportionate to lateral velocity; max speed 2.5 in/sec = 30 kts.	

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TABLE 5 - SUMMARY OF VSD INFORMATION FOR TAKEOFF

	F-111B HUD	F-111B DVI	A-6A ADI	AAAIS VSD	A-7D/E HUD	ILAAS HUD	ILAAS VSD	Norden IEVD	IHAS VDI	VSTOL HUD/VSD
PITCH ANGLE	✓	✓	✓	✓	✓	✓	✓	✓	✓	
PITCH TRIM	✓	✓	✓	✓			✓			
ANGLE OF ATTACK			✓		✓	✓				
ROLL ANGLE	✓	✓	✓	✓	✓	✓	✓	✓	✓	
HEADING	✓	✓			✓		✓	✓	✓	
STEERING	✓	✓	✓	✓	✓	✓	✓	✓	✓	
TURN RATE								✓		
VERTICAL ORIENTATION	✓	✓	✓	✓	✓		✓	✓	✓	
ALTITUDE	✓	✓		✓	✓		✓	✓	✓	
VERTICAL VELOCITY	✓				✓			✓	✓	
AIRSPEED		✓		✓	✓			✓	✓	
VELOCITY VECTOR			✓	✓	✓	✓	✓		✓	
PULL-UP										
GLIDESLOPE										
GLIDEPATH										
WAVEOFF										
PATHWAY										
SIDESLIP										
RUNWAY HEADING ERROR				✓				✓		
RUNWAY DISTANCE								✓		
HOVER POSITION										
RANGE TO GO										
GROUNDSPEED									✓	
HOVER GROUNDSPEED								✓	✓	
LATERAL GROUND VELOCITY								✓	✓	

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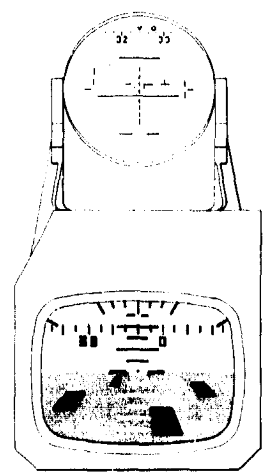
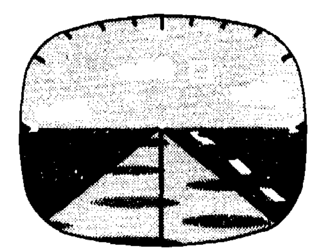
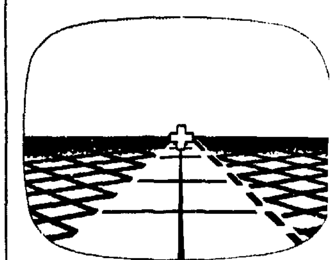
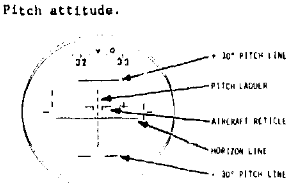
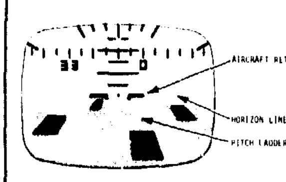
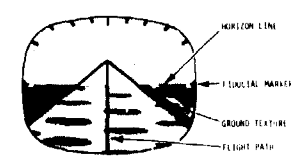
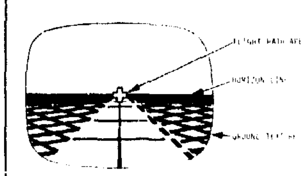
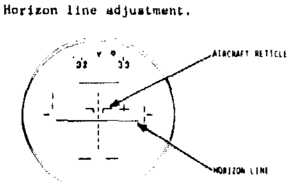
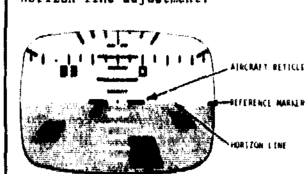
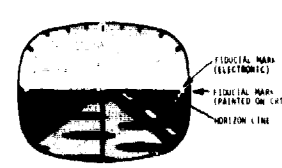
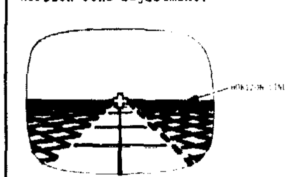
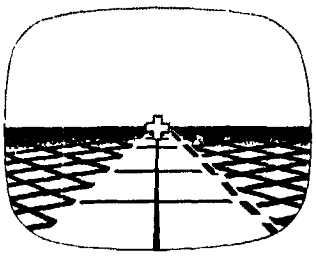
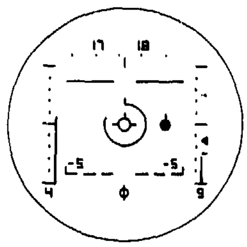
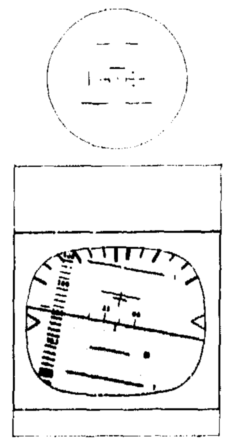
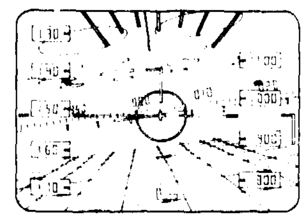
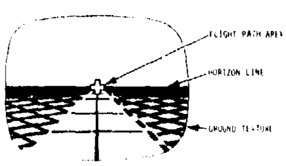
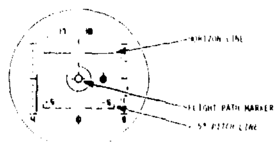
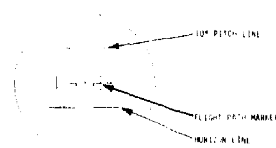
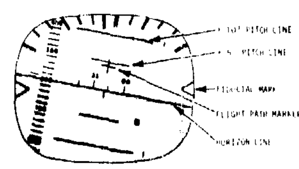
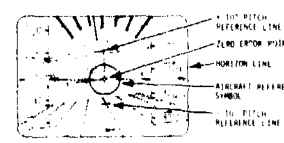
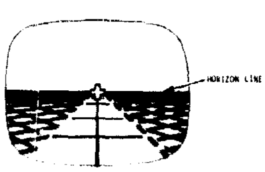
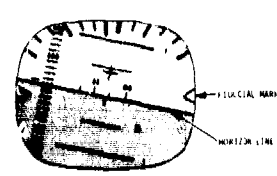
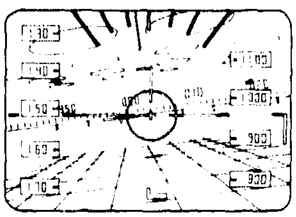
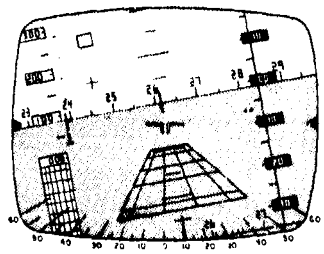
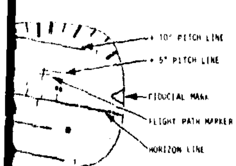
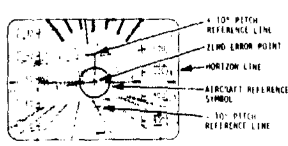
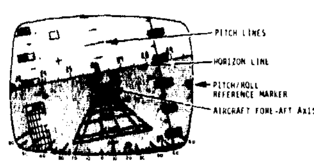
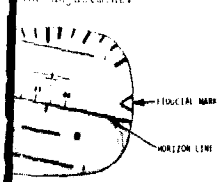
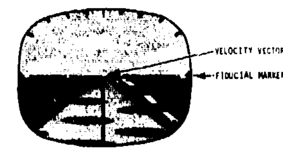
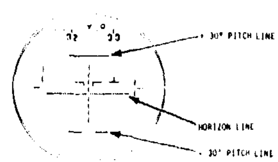
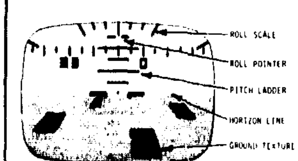
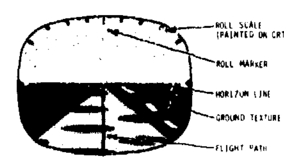
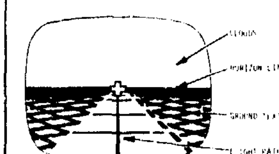
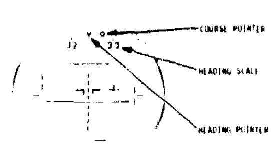
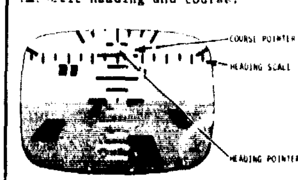
TABLE 6 - ANALYSIS OF VSDs FOR EN ROUTE

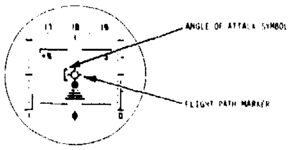
EN ROUTE					
					
VSD DISPLAYS		**F-111B** FIXED WING **HUD**	**F-111B** FIXED WING **DVI**	**A-6A** FIXED WING **ADI**	**AAAIS** FIXED WING **VSD**
PITCH ANGLE	**INFORMATION**	Pitch attitude.	Pitch attitude.	Pitch attitude.	Pitch attitude.
	SYMBOLOGY				
	DESCRIPTION	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol.	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol.	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at display center.	Horizon line moves vertically as a function of aircraft pitch angle with respect to horizontal reference plane.
	RESPONSE	Inside-out.	Inside-out.	Inside-out.	Inside-out.
	SCALING	Approximately $\pm$ 30° vertical coverage. Scale factor 1:6 (compression).	Approximately $\pm$ 30° vertical coverage. Scale factor 1:6 (compression).	$\pm$ 15° vertical coverage. Scale Factor 1:2.5 (compression).	$\pm$ 9° vertical coverage. Scale factor 1:1.
	REMARKS	Pitch ladder shows 5° increments 0 to $\pm$ 20°. Auxiliary pitch lines at + 30° (solid line) and - 30° (broken line). Nadir and Zenith not displayed.	Pitch ladder shows 10° major and 5° minor increments 0 to + 30°. Auxiliary pitch lines, at $\pm$ 30°, $\pm$ 60°, and + 90° (not shown), are color coded: black for positive, white for negative.	Auxiliary pitch lines, at $\pm$ 30°, $\pm$ 60° and $\pm$ 90° (not shown), are color coded: black for positive, white for negative.	Display center is not marked. No scal provided for quantitative reading of pitch angle.
PITCH TRIM	**INFORMATION**	Horizon line adjustment.	Horizon line adjustment.	Fiducial marker adjustment.	Horizon line adjustment.
	SYMBOLOGY				
	DESCRIPTION	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.	A manual control permits vertical adjustment of fiducial markers to compensate for differences in pitch attitude for various conditions of level flight.	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.
	RESPONSE				
	SCALING	Range of adjustment $\pm$ 20°.	Range of adjustment $\pm$ 15°.	Range of adjustment $\pm$ 15°.	Range of adjustment $\pm$ 6°.
	REMARKS	The local horizon is used for level flight reference.	The local horizon is used for level flight reference.		Detent in manual control used for level flight reference.

A

AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD
				
Pitch attitude.  Horizon line moves vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Inside-out. $\pm$ 9° vertical coverage. Scale factor 1:1. Display center is not marked. No scale provided for quantitative reading of pitch angle.	Flight path angle.  Horizon and pitch lines move vertically with respect to flight path marker to indicate flight path angle (pitch minus angle of attack). Level flight when horizon and flight path marker coincide. Inside-out. Scale factor 1:1. Auxillary reference lines at $\pm$ 5°, $\pm$ 10° and thereafter at 5° intervals to $\pm$ 90°. Pitch angle not displayed. Flight path marker is velocity vector terminus.	Flight path angle.  Horizon and pitch lines move vertically with respect to flight path marker to indicate flight path angle (pitch minus angle of attack). Level flight when horizon and flight path marks coincide. Inside-out. Scale factor 1:1. Pitch scale centers on unmarked display boresight but is read at flight path marker. Pitch lines at $\pm$ 10°, $\pm$ 30°, $\pm$ 50° and $\pm$ 70°. Pitch angle not displayed. Flight path marker = velocity vector.	Pitch attitude.  Horizon line and pitch line move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read from fiducial marks. Inside-out. Scale factor about 1:2.5 (compression). Pitch scale has $\pm$ 10°, $\pm$ 30°, $\pm$ 50° and $\pm$ 70° marked with 1, 3, 5 and 7 respectively; nadir, - 90°, is an open cross; zenith, + 90°, a closed cross that resembles flight director command symbol.	Pitch attitude.  Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol. Inside-out. Scale factor 1:5 (compression). Pitch ladder shows $\pm$ 10°.
Horizon line adjustment.  A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight. Range of adjustment $\pm$ 6°. Detent in manual control used for level flight reference.	B		Horizon line adjustment.  A manual control permits vertical adjustment of the horizor line to compensate for differences in pitch attitude for various conditions of level flight. Range of adjustment + 10° to -20°. The local horizon is used for level flight reference.	

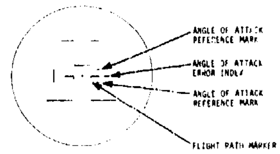
S FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
			All Weather VSTOL display is not shown in the en route phase.
itude. 	Pitch attitude. 	Pitch attitude. 	
...ine and pitch line move verti- ...a function of aircraft pitch ...respect to horizontal refer- ...e. Pitch read from fiducial	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol.	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read from pitch and roll reference marks.	
...t.	Inside-out.	Inside-out.	
...tor about 1:2.5 (compression).	Scale factor 1:5 (compression).	Display represents ± 27° of pitch. Scale factor 1:5 (compression).	
...le has + 10°, + 30°, + 50° and ...ked with 1, 3, 5 and 7 respec- ...lir, + 90°, is an open cross; ..., a closed cross that re- ...ght director command symbol.	Pitch ladder shows ± 10°.	Pitch scale has ± 5° and ± 10° increments continuously through range.	
...ion adjustment.  ...control permits vertical ad- ...t the horizon line to compen- ...ifferences in pitch attitude ...conditions of level flight. ...justment + 10° to -20°. ...l horizon is used for level ...eference.			Preceding page blank

VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD	A
ANGLE OF ATTACK	INFORMATION			Angle of attack.		
	SYMBOLOGY					
	DESCRIPTION			Angle of attack shown by vertical separation of velocity vector symbol and imaginary line between fiducial markers.		
	RESPONSE			Inside-out, status.		
	SCALING			Scale factor 1:2.5 (compression).		
	REMARKS					
ROLL ANGLE	INFORMATION	Roll attitude.	Roll attitude.	Roll attitude.	Roll attitude.	
	SYMBOLOGY					
	DESCRIPTION	Horizon line and pitch lines rotate to indicate roll.	Horizon line, pitch lines, and ground features rotate to indicate roll. Quantitative information provided by roll pointer and reference marks.	Horizon line, pitch lines, sky and ground features, and flight path rotate to indicate roll. Quantitative information provided by roll pointer and reference marks.	Horizon line, flight path, and sky and ground features rotate to indicate roll.	
	RESPONSE	Inside-out, status.	Inside-out, status.	Inside-out, status.	Inside-out, status.	
	SCALING	Scale factor 1:1.	Scale factor 1:1.	Scale factor 1:1.	Scale factor 1:1.	
	REMARKS	Peripheral scales are aircraft-stabilized (do not roll). No scale marks for quantitative reading of roll angle.	Peripheral scales are earth-stabilized (roll with horizon) Roll reference marks at ± 10°, ± 20°, ± 30° and ± 60°.	Roll reference marks at 15° increments 0 to ± 60°.	No scale marks for reading of roll angle.	
HEADING	INFORMATION	Magnetic heading and course.	Magnetic heading and course.			
	SYMBOLOGY					
	DESCRIPTION	Heading tape moves to indicate actual heading. Read at fixed index. Course pointer moves along scale to indicate actual course.	Heading tape moves to indicate actual heading. Read at roll pointer. Course pointer moves along scale to indicate actual course.			
	RESPONSE	Inside-out, status.	Inside-out, status.			
	SCALING	Coverage about 16°. Scale factor 1:3.2 (compression).	Coverage 75°. Scale factor 1:6 (compression).			
	REMARKS A	Scale marks at 2° increments with numerals every 10°. Manually selectable on or off.	Scale marks at 10° major and 5° minor with numerals every 30°. Heading scale is black with steering commands present and white without steering when scale is primary reference. Manual on/off.			

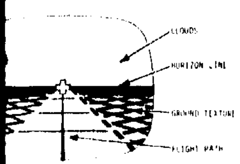
<table>
<tr><th>AIS FIXED WING VSD</th><th>A-7D/E FIXED WING HUD</th><th>ILAAS FIXED WING HUD</th><th>ILAAS FIXED WING VSD</th><th>Norden ROTARY WING FIXED WING IEVD</th><th>IHAS</th></tr>
<tr>
<td></td>
<td>Status angle of attack.

AOA symbol is fixed. Position of flight path marker in relation to it indicates actual AOA.

Status, fly-from.

Length of bracket = 2 units AOA.

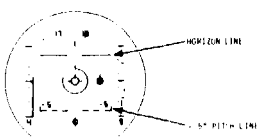
Center of AOA symbol represents nominal value of 17.5 units. AOA symbol blanked whenever AOA less than 12 units.</td>
<td>Deviation from command angle of attack.

AOA error index moves vertically with reference to the right wing of the flight path marker to indicate AOA error. AOA reference marks are fixed with respect to the flight path marker.

Fly-from. A high symbol indicates a + AOA error and is a command to decrease.

Not specified.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...attitude.

...line, flight path, and sky and ...features rotate to indicate

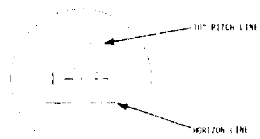
...al, status.

...factor 1:1.

...marks for reading of roll</td>
<td>Roll attitude.

Horizon line and pitch lines rotate to indicate roll.

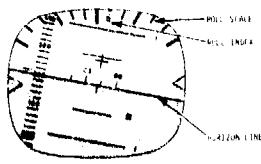
Inside-out, status.

Scale factor 1:1.

Peripheral scales are aircraft stabilized (do not roll). No scale marks for quantitative reading of roll angles.</td>
<td>Roll attitude.

Horizon line and pitch lines rotate to indicate roll.

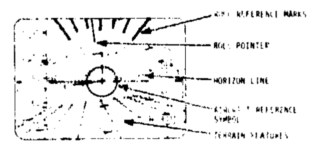
Inside-out, status.

Scale factor 1:1.

Though not specified, it is assumed that horizon and pitch lines rotate about the unmarked display center (boresight).</td>
<td>Roll attitude.

Horizon line and pitch lines rotate to indicate roll. Quantitative information provided by roll pointer and reference marks.

Inside-out, status.

Scale factor 1:1.

Peripheral scales are earth stabilized (roll with horizon). Reference marks at 10° intervals, 0° to 60°.</td>
<td>Roll attitude.

Horizon line, pitch lines, and sky and ground features rotate to indicate roll. Quantitative information provided by roll pointer and reference marks.

Inside-out, status.

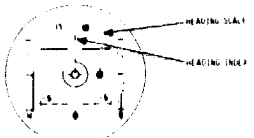
Scale factor 1:1.

Peripheral scales are aircraft stabilized (do not roll). Reference marks at 0°, ± 10°, ± 20°, ± 30° and ± 60° roll angles.</td>
<td>Roll attitude...

Horizon line ... indicate roll...

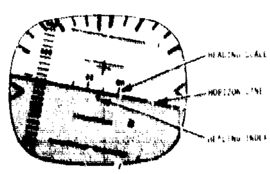
Inside-out, ...

Scale factor ...

Peripheral sc... (roll with ho... in 5° minor an...</td>
</tr>
<tr>
<td></td>
<td>Magnetic heading.

Heading tape moves horizontally to indicate actual heading. Read at the fixed heading index.

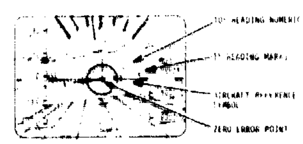
Inside-out, status.

Scale factor 1:4.4.

Heading not displayed in decluttered mode.</td>
<td></td>
<td>Magnetic heading.

Heading tape on horizon moves to indicate actual heading. Read at fixed heading index marker.

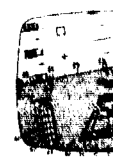
Inside-out, status.

Scale factor approximately 1:2.5 (compression).

Scale marks in 5° increments with numerals every 10°. Heading scale also appears on ± 30° pitch lines.</td>
<td>Magnetic heading.

Heading tape moves along horizon to indicate actual heading. Read at zero error point (center of aircraft reference symbol).

Inside-out, status.

30° coverage. Scale factor 1:4 (compression).

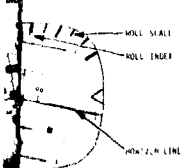
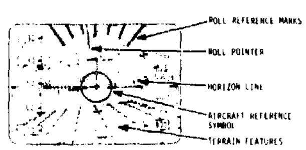
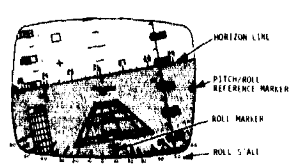
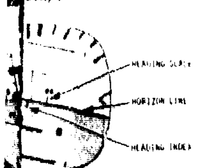
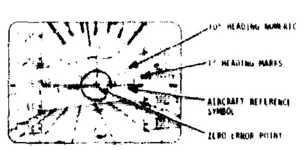
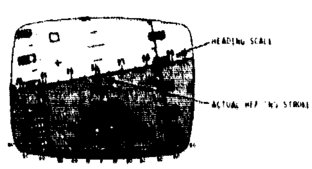
Scale marks at 1° increments, with numerals every 10°. Changes in heading also indicated by movement and changes in orientation of ground texture.</td>
<td>Magnetic head...

Heading tape ... cate actual h... section of ac...

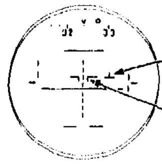
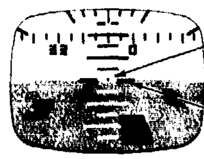
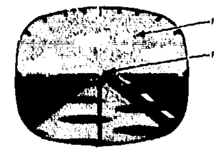
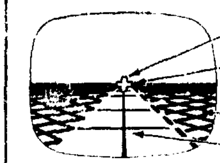
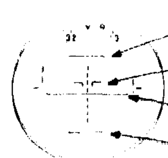
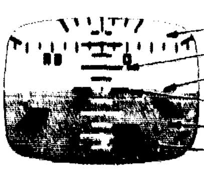
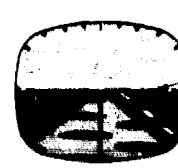
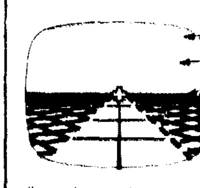
Inside-out, st...

Scale factor ...

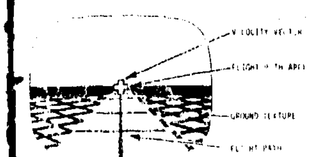
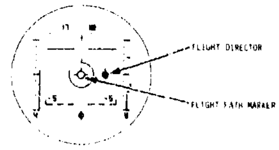
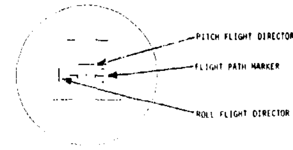
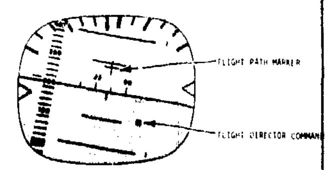
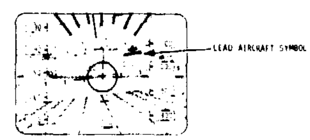
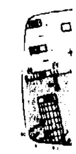
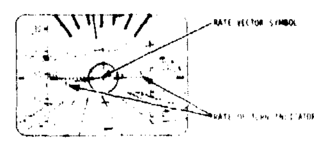
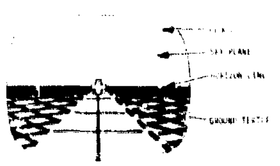
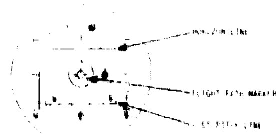
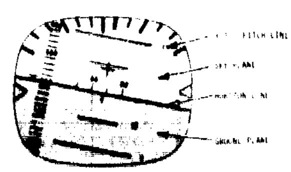
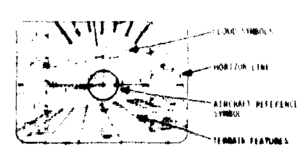
Scale marks ... erals every 1... appears on ±...</td>
</tr>
</table>

B

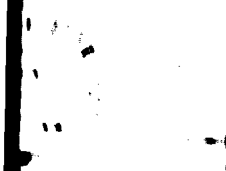
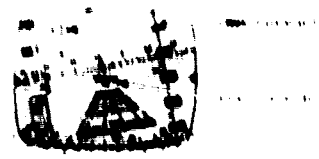
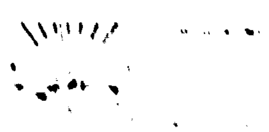
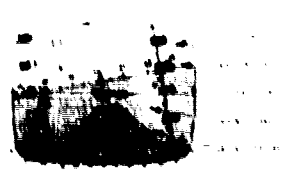
FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
	Roll attitude. 	Roll attitude. 	
... and pitch lines rotate to ... quantitative information ... pointer and reference	Horizon line, pitch lines, and sky and ground features rotate to indicate roll. Quantitative information provided by roll pointer and reference marks.	Horizon line and pitch lines rotate to indicate roll.	
... status.	Inside-out, status.	Inside-out, status.	
... 1:1.	Scale factor 1:1.	Scale factor 1:1.	
... ales are earth stabilized ... horizon. Reference marks at ... 0° to 60°.	Peripheral scales are aircraft stabilized (do not roll). Reference marks at 0°, ± 10°, ± 20°, ± 30° and ± 60° roll angles.	Peripheral scales are earth stabilized (roll with horizon). Roll scale marked in 5° minor and 10° major increments.	
... ding. 	Magnetic heading. 	Magnetic Heading. 	
... on horizon moves to indi- ... ading. Read at fixed ... marker.	Heading tape moves along horizon to indicate actual heading. Read at zero error point (center of aircraft reference symbol).	Heading tape on horizon moves to indicate actual heading. Read at intersection of actual heading stroke.	
... tatus.	Inside-out, status.	Inside-out, status.	Preceding page blank
... approximately 1:2.5 (com-	50° coverage. Scale factor 1:4 (compression).	Scale factor 1:5.	
... 5° increments with numer- ... Heading scale also ap- ... pitch lines.	Scale marks at 1° increments, with numerals every 10°. Changes in heading also indicated by movement and changes in orientation of ground texture.	Scale marks in 5° increments with numerals every 10°. Heading scale also appears on ± 30° pitch lines.	C 55

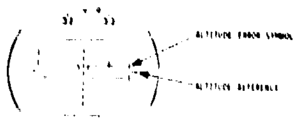
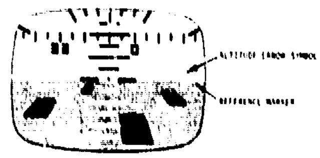
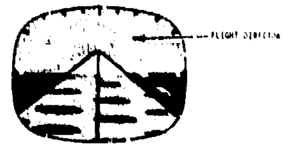
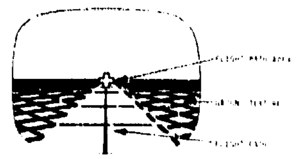
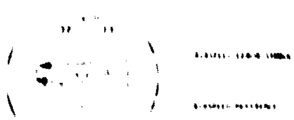
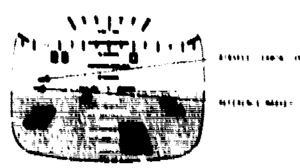
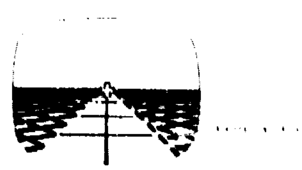
	VSD DISPLAYS	F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
STEERING	INFORMATION	Command heading.	Command heading.	Command pitch and roll.	Command heading.
	SYMBOLOGY				
	DESCRIPTION	Symbol displaced from null position at aircraft reticle to indicate required changes in heading.	Symbol displaced from null position at aircraft reticle to indicate required changes in heading.	Pathway and flight director symbols displaced from null position at display center to indicate required changes in heading and/or pitch.	Lateral translation and rotation of flight path symbol about apex indicates deviation from command heading.
	RESPONSE	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command.
	SCALING	Scale factor 1:6 (compression).	Scale factor 1:6 (compression). 1 inch = 11°.	Scale factor 1:3.3 (compression horizontally and vertically.	Total coverage approximately ± 11°. Scale factor 1:1.
	REMARKS	Simple displacement commands. Symbol limits at ± 25° of heading error. Symbol can also indicate pitch commands given such inputs.	Simple displacement commands. Symbol limits at ± 25° of heading error. Symbol can also indicate pitch commands given such inputs.	Steering commands based on displacement and rate— roll sum and pitch sum steering. Flight path apex shows direction and magnitude of required change. Flight director shows rate and error summed.	Apex limits at display edge. Status indication of heading change also provided by lateral movement of ground and sky elements.
TURN RATE	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS	Qualitative indication of turn rate provided by rate of movement of magnetic heading scale.	Qualitative indication of turn rate provided by rate of lateral movement of magnetic heading scale and ground texture.	Qualitative indication of turn rate provided by rate of lateral movement of ground texture.	Qualitative indication of turn rate provided by rate of lateral movement of ground texture.
VERTICAL ORIENTATION	INFORMATION	Vertical orientation.	Vertical orientation.	Vertical orientation.	Vertical orientation.
	SYMBOLOGY				
	DESCRIPTION	+ 30° pitch line is solid. - 30° pitch line is broken.	Sky and ground are differentiated by gray tone shading and by ground texture elements. Tail of steering symbol always points up; roll pointer points down.	Sky and ground are differentiated by gray tone shading, clouds, ground texture elements, and pitch line coding.	Sky and ground are differentiated by ground texture grid and clouds.
	RESPONSE	Inside-out, status.	Inside-out, status.	Inside-out, status.	Inside-out, status.
	SCALING	N.A.	N.A.	N.A.	N.A.
	REMARKS	Vertical orientation cues not shown on display in pitch attitudes beyond ± 50°.	Major pitch lines are color coded; black for positive; white for negative pitch angles. Perspective of ground texture elements indicates direction of nearest horizon in nose-down attitude.	Perspective of ground texture elements indicates direction of nearest horizon in nose-down attitude.	Perspective of ground texture grid indicates direction of nearest horizon in nose-down attitude.

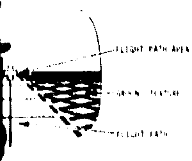
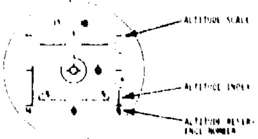
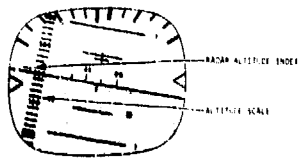
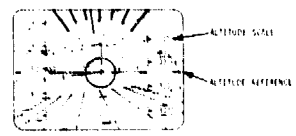
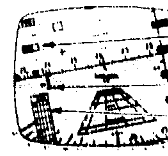
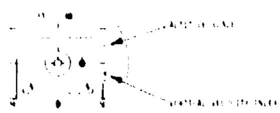
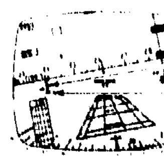
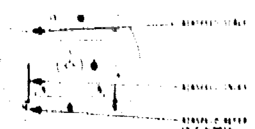
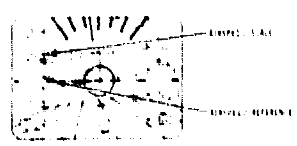
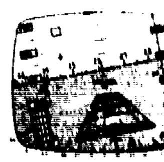
A

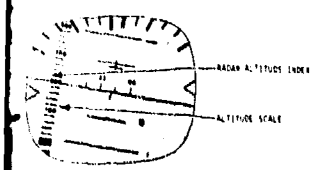
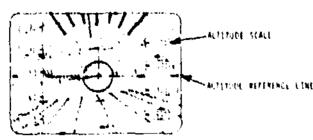
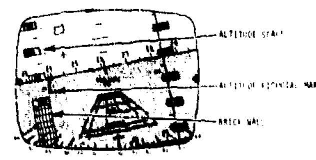
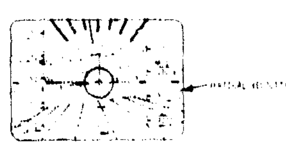
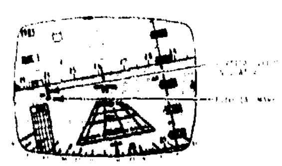
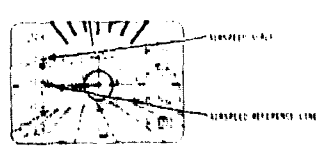
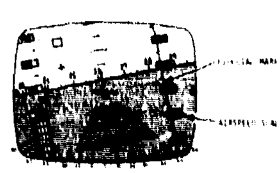
AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	HA
Command heading.	Command heading and pitch.	Command heading and pitch.	Command heading and pitch.	Command heading, pitch, roll.	Command
					
Lateral translation and rotation of flight path symbol about apex indicates deviation from command heading.	Flight director symbol displaced from null position at flight path marker to indicate required changes in heading.	Two flight director components are driven individually from null position at flight path marker to indicate required changes in heading and/or pitch.	Two flight director components are driven individually from null position at flight path marker to indicate required changes in heading and/or pitch.	Symbol displaced from null position at display center to indicate required changes in heading, pitch, and/or roll. Can also rotate about its axis at any point to indicate bank command.	Comman' f'om nu s'mbol heading
Fly-to, command.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to,
Total coverage approximately ± 11°. Scale factor 1:1.	Not specified.	Not specified.	Not specified.	Not specified.	Not spe
Scale limits at display edge. Status indication of heading change also provided by lateral movement of ground and sky elements.		"Roll" flight director commands heading change rather than roll. Both flight director components are combined into a cross (flight director symbol) when simultaneous heading and pitch commanded.	The flight director command consists of a pitch flight director symbol and a "roll" flight director symbol. The latter commands changes in heading, not roll.	Normally a zero-reader symbol, but can also be used as a predictor (future status) or rate command symbol. Can also be varied in size or shape to provide additional command cues.	In vert vector the re te a r in l
				Rates of turn.	
					
				A "rate vector" symbol, originating from center of horizon, extends to left or right by an amount proportional to rate of turn. Reference marks designate 1-, 2-, & 4-min turns.	
				Status. Markings move to the right for a right turn.	
				1, 2, and 4 minute turn rates.	
Qualitative indication of turn rate provided by rate of lateral movement of ground texture.	Qualitative indication of turn rate provided by rate of movement of heading scale.		Qualitative indication of turn rate provided by rate of movement of heading scale.	Rate of turn markers move independently of heading scale.	Qualit provi of gro
Vertical orientation.	Vertical orientation.		Vertical orientation.	Vertical orientation.	Vertic
					
Sky and ground are differentiated by ground texture grid and clouds.	Minus pitch lines are dashed and marked with negative numerals; plus pitch lines are solid and marked with numerals.		Sky and ground texture are differentiated by grey tone shading. Pitch lines are marked with numerics. Zenith and nadir are a closed and open cross respectively.	Sky and ground texture are differentiated by gray tone shading, cloud symbols and a grid pattern.	Sky an ated b elemen
Inside-out, status.	Inside-out, status.		Inside-out, status.	Inside-out, status.	Inside
N.A.	N.A.		N.A.	N.A.	N.A.
Perspective of ground texture grid indicates direction of nearest horizon in nose-down attitude.	All pitch scale numerics are earth stabilized. Hence, if they appear upside down, they indicate an inverted attitude.		All numerals are earth stabilized. Hence, if they appear upside down, they indicate an inverted attitude.	All numerics are earth stabilized. If they appear upside down, they indicate an inverted attitude. Ground texture perspective indicates location of nearest horizon in nose-down attitude.	All nu Grounc cates nose-d

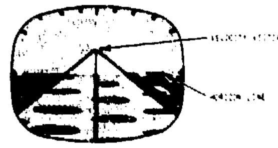
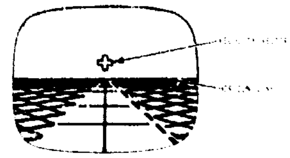
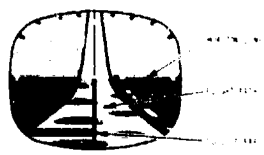
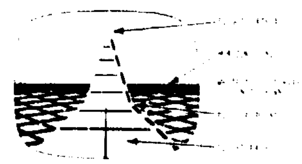
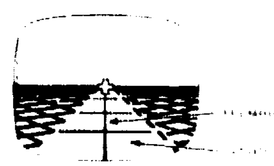
B

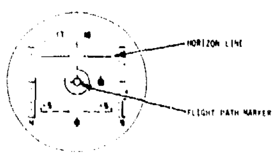
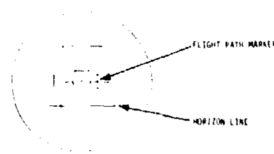
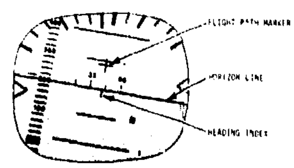
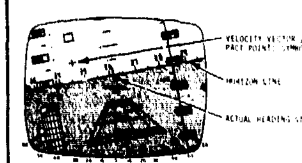
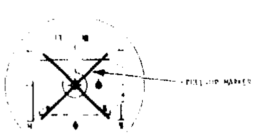
VSD	Norden IEVD	IHAS VDI	VSTOL HUD/VSD
 [illegible]	[illegible]  [illegible]	[illegible]  [illegible]	
[illegible]	[illegible]  [illegible]	[illegible]	
 [illegible]	[illegible]  [illegible] ... indicates location of nearest horizon in nose down attitude	[illegible]  [illegible]	Preceding page blank

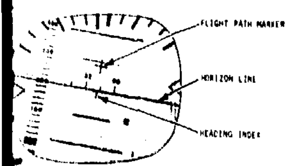
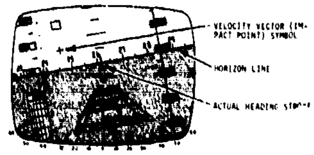
VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD	A
ALTITUDE	INFORMATION	Command altitude.	Command altitude (barometric).	Command altitude.	Command altitude.	
	SYMBOLOGY					
	DESCRIPTION	Error symbol moves vertically from fixed reference mark to indicate deviation from command altitude. At null position gap in symbol is centered on reference mark.	Error symbol moves vertically from fixed reference mark to indicate deviation from command altitude. At null position gap in symbol is centered on reference mark.	Vertical displacement of flight director symbol from aircraft reticle presents quickened altitude holding commands.	Ground texture and pathway provide altitude reference plane. Size and pattern of ground texture elements vary with status altitude. Pathway varies as deviation from command altitude.	
	RESPONSE	Fly-to, command.	Fly-to, command.	Fly-to. Upward symbol movement commands altitude increase and/or rate of climb.	Pilot controls altitude so that pathway appears to be at fixed altitude below.	
	SCALING	Scale factor 1" = approximately 500 ft of altitude error	Scale factor 1 inch equals 800 ft altitude error.	Not specified.	White ground lines on black: 0-100 ft & over 1000 ft; black on white: 100-1000.	
	REMARKS	Manually selectable on or off. Altitude also read to nearest 100 ft on counter above DVI.	Manually selectable on or off. Altitude also read to nearest 100 ft. on counter above DVI.		When aircraft above command altitude, pathway narrows. When below command altitude, pathway widens and eventually flips to top of display so as to appear over aircraft.	
VERTICAL VELOCITY	INFORMATION					
	SYMBOLOGY					
	DESCRIPTION					
	RESPONSE					
	SCALING					
	REMARKS				No quantitative indication of vertical velocity; however, pathway display is programmed for both altitude error and command rate of change.	
AIR SPEED	INFORMATION	Command airspeed.	Command airspeed.		Command airspeed	
	SYMBOLOGY					
	DESCRIPTION	Error symbol moves vertically from fixed reference mark to indicate deviation from command airspeed. At null position gap in symbol is centered on reference mark.	Error symbol moves vertically from fixed reference mark to indicate deviation from command airspeed. At null position gap in symbol is centered on reference mark.		Movement of dashed lines on right of flight path indicates deviation from command airspeed.	
	RESPONSE	Command, fly-from (upward displacement of symbol commands airspeed decrease).	Command. Fly-from (upward symbol displacement commands decrease in airspeed.		Command. Fly-to.	
	SCALING	Scale factor 1" = approximately 50 kts.	Scale factor 1 inch equals 80 kts		Relation of rate of movement to magnitude of error not specified	
	REMARKS	Airspeed also read to nearest 10 kts on on counter above DVI.	Airspeed also read to nearest 10 kts on a counter above DVI.		When actual airspeed equals command airspeed, the dashed lines are stationary. When actual greater than command, lines move downward, and vice versa.	

FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTAR
 ...e and pathway provide alti-... plane. Size and pattern ... elements vary with ...de. Pathway varies as ... command altitude. ...altitude so that pathway ... altitude below. ...black: 0-100 ft & ... white: 100-1000. ... command altitude, ... below command al-... and eventually ... display so as to appear	Status and command altitude.  Altitude scale fixed. Thermometer type indexer moves on scale. The number at the scale base (e.g. 9) indicates the scale begins at 9000 ft. Status. Not specified. 1000 ft scale structure has 100 ft increments with major marks every 250 ft. Radar or barometric altitude is displayed depending on mode. Max range not specified.		Status altitude.  Altitude tape moves against fixed reference line to provide quantitative altitude information. Status. Tape moves downward for increase in altitude. Scale factor 100 ft/in. Scale has 20 feet increments with numerics every 100 ft to 5000 ft. There are 400 ft of scale in view at any one time. "Brick wall" appears at 0 ft. Scale is earth stabilized (rolls with horizon).	Altitude.  Altitude tape moves against fixed reference line to provide quantitative altitude information. Status. Tape moves downward for increased altitude. 1 raster line equals 1 foot altitude or approx. 60 feet per inch. Scale has 100 ft increments. Barometric or radar altitude not specified (either may be used).	Status radar altitude  Movable vertical tape ... ed fiducial marker ... titude. Status. Tape moves ... creased altitude. 400 ft of scale in ... 20 ft increments ... Scale not displayed ... "Brick wall" appear... rolls with raster ...
...indication of vertical ..., pathway displacement ... altitude error ...	Rate of ascent/descent.  Fixed scale and moving pointer indicate vertical velocity. Status. Not specified. Altitude scale also serves as vertical velocity scale.			Rate of ascent/descent.  Vertical velocity represented by bar extending from altitude reference mark. Length of bar proportional to vertical velocity. Status. bar extends upward for ascent; downward for descent. Not specified.	Rate of ascent/descent  Vertical velocity ... nating from altitude ... Length of bar propor... velocity. Status. Bar extend... downward for descent Scale factor 1 in ... Index marks at 100 ... Range ± 400 fpm.
 ... flight of ... orientation ... ... to magni... ... command air ... are stationary ... command, lines ... versa.	Status airspeed.  Airspeed scale fixed. Thermometer type indexer moves on scale to provide quantitative airspeed. The number at the base of the scale (e.g., 4) indicates the scale begins at 400 kts. Status. Not specified. Scale has 10 knot increments with dots every 5 knots and major marks every 50 knots. Max. range not specified. Airspeed not displayed in decluttered mode.	B		Status airspeed.  Moving vertical tape read against fixed reference line indicates status airspeed. Status. Tape moves upward with increased airspeed. Not specified. Note airspeed and altitude tapes move in opposite direction for increasing values. Numerals at 10 kt intervals from - 50 to + 570 kts.	Status airspeed.  Movable vertical tape ... ed fiducial marker ... Status. Tape moves ... crease in airspeed. Scale factor 10 kts ... 5 kt scale increments ... ary 10 kts. ... kts ... at any given time. ... indicated by minus ... groundspeed.)

ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
Status altitude.  Altitude tape moves against fixed reference line to provide quantitative altitude information. Status. Tape moves downward for increase in altitude. Scale factor 200 ft/in. Scale has 20 feet increments with numerics every 100 ft to 5000 ft. There are [illegible] of scale in view at any one time. "Brick wall" appears at 0 ft. Scale is earth stabilized (rolls with horizon).	Altitude.  Altitude tape moves against fixed reference line to provide quantitative altitude information. Status. Tape moves downward for increased altitude. 1 raster line equals 1 foot altitude or approx. 60 feet per inch. Scale has 100 ft increments. Barometric or radar altitude not specified (either may be used).	Status radar altitude.  Movable vertical tape read against fixed fiducial marker indicates radar altitude. Status. Tape moves downward for increased altitude. 400 ft of scale in view at any one time; 50 ft increments; numerics every 100 ft. Scale not displayed above 5000 ft. "Brick wall" appears at 0 ft. Scale rolls with raster (earth stabilized).	
	Rate of ascent/descent.  Vertical velocity represented by bar extending from altitude reference mark. Length of bar proportional to vertical velocity. Status. Bar extends upward for ascent; downward for descent. Not specified.	Rate of ascent/descent.  Vertical velocity displayed by bar emanating from altitude fiducial marker. Length of bar proportional to vertical velocity. Status. Bar extends upward for ascent; downward for descent. Scale factor 1 in = 200 fpm. Index marks at 100 fpm increments. Range ± 400 fpm.	
	Status airspeed.  Moving vertical tape read against fixed reference line indicates status airspeed. Status. Tape moves upward with increased airspeed. Not specified. Note airspeed and altitude tapes move in opposite direction for increasing values. Numerals at 10 kt intervals from - 50 to + 570 kts.	Status airspeed.  Movable vertical tape read against fixed fiducial marker indicates airspeed. Status. Tape moves downward for increase in airspeed. Scale factor 10 kts/in. 5 kt scale increments with numerals every 10 kts. 40 kts of scale in view at any given time. Negative airspeed indicated by minus sign. (See also groundspeed.)	Preceding page blank

VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
VELOCITY VECTOR	INFORMATION			Actual flight path through the airmass.	Actual flight path through the airmass.
	SYMBOLOGY				
	DESCRIPTION			The position of the velocity vector symbol with respect to the horizon line and/or the flight path apex denotes the actual flight path or velocity vector of the aircraft.	The position of the velocity vector symbol with respect to the horizon line and/or the flight path apex denotes the actual flight path or velocity vector of the aircraft.
	RESPONSE			Fly-from (velocity vector flown from present position to desired position).	Fly-from (velocity vector flown from present position to the desired position).
	SCALING			Vertical scale factor 1:2.5; horizontal scale factor 1:3.3 (both compression).	Scale factor 1:1.
	REMARKS			The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.	The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.
PULL-UP	INFORMATION			Pull-up command.	Pull-up command.
	SYMBOLOGY				
	DESCRIPTION			Pathway apex is displaced upward abruptly to command a pull-up maneuver. For a planned pull-up, a downward moving bar serves as an anticipatory command.	Pathway apex is displaced upward abruptly to command a pull-up maneuver. For a planned pull-up, a downward moving [illegible] marker serves as anticipatory command.
	RESPONSE			Fly-to, command.	Fly-to, command.
	SCALING			Variable.	Not specified.
	REMARKS			Pull-up based on aircraft closure speed and pull-up "g" required for weapon delivery.	The "flipped" flight path [illegible] is considered a form of pull-up [illegible] at low altitude.
PATHWAY	INFORMATION				Course and/or ground track [illegible].
	SYMBOLOGY				
	DESCRIPTION				The aircraft is on course when pathway center line (course marker) is vertical and aligned with [illegible] center [illegible] error shown by rotation and translation of pathway.
	RESPONSE				Fly-to.
	SCALING				[illegible] selectable [illegible]
	REMARKS				Selected course may be present [illegible] preset map course, homing [illegible] may aid [illegible] steering [illegible] aid or selected radial [illegible] earth, aircraft or air mass [illegible].

VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VD
the airmass.	Actual flight path through the airmass.	Actual flight path through the airmass.	Actual flight path through the airmass.		Actual flight path through the airmass
					
...vector sym- ...zon line ...denotes the ...ity vector	The position of the flight path marker with respect to the horizon line denotes the actual flight path or velocity vector of the aircraft.	Flight path marker denotes actual flight path or aircraft velocity vector. Drift is its lateral displacement from center. The horizon line position in relation to it indicates aircraft flight path.	The position of the flight path marker with respect to the horizon line and heading index denotes the actual flight path or velocity vector of the aircraft.		Position of velocity vector symbol in relation to horizon line and actual heading stroke indicates actual path of aircraft through the airmass.
...lown from the ...ired position)	Fly-to (fixed flight path marker flown from present position to horizon line).	Fly-to (flight path marker flown to moving horizon line).	Fly-from (flight path marker flown from present position to desired position).		Fly-from.
	Not specified.	Not specified.	Not specified.		Not specified.
...point of ...it the ...e aircraft	In this mechanization, the flight path position represents the terminus of the aircraft velocity vector with respect to the real world.	In this mechanization, the flight path is represented by the relation between the flight path marker and horizon symbols. Neither symbol position displayed is directly related to the real world.	The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.		During vertical ascent or descent, sy... bol will be off display. Dynamics of symbol during hover not specified.
	Pull-up command.				
					
...sharply ... For a ...ing white ...command.	Pull-up indicated by large flashing X at display center.				
	Discrete.				
	N.A.				
...should also ...ll-up command	Pull-up command appears automatically if terrain following system fails.				
...paths ...s vertical ... course ...ription					
...at course, ...direct route ...to nav ...always can be ...tilized.	B				Pre

LAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
...ual flight path through the airmass.  ...position of the flight path marker ...th respect to the horizon line and ...ne index denotes the actual flight ... velocity vector of the aircraft. ...-from (flight path marker flown from ... position to desired position). ...t specified. ... symbol marks the projected point of ... on the ground-sky plane if the ...tion and velocity of the aircraft ... not changed.		Actual flight path through the airmass.  Position of velocity vector symbol in relation to horizon line and actual heading stroke indicates actual path of aircraft through the airmass. Fly-from. Not specified. During vertical ascent or descent, symbol will be off display. Dynamics of symbol during hover not specified.	

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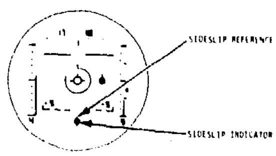
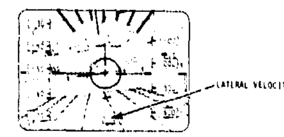
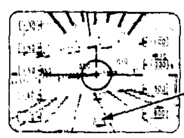
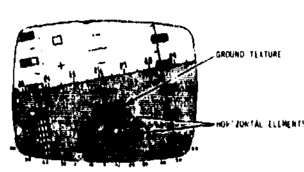
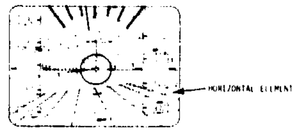
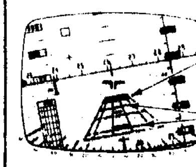
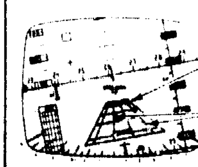
VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VS
SIDESLIP	INFORMATION SYMBOLOGY				
	DESCRIPTION				
	RESPONSE SCALING				
	REMARKS				
RANGE TO GO	INFORMATION SYMBOLOGY				
	DESCRIPTION				
	RESPONSE SCALING				
	REMARKS				
GROUNDSPEED	INFORMATION SYMBOLOGY				
	DESCRIPTION				
	RESPONSE SCALING				
	REMARKS	A			

AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHA
	Lateral velocity.  The sideslip indicator moves right and left from fixed reference to indicate lateral velocity. Status. Indicator moves right for sideslip to the right. Not specified. Sideslip displayed only in attack mode.			Lateral velocity (see remarks).  Rate vector, originating from the display center at the bottom of the viewing area, extends left or right in proportion to lateral velocity. Vector moves right for lateral velocity to the right. About 10 knots per inch. Lateral velocity for rotary wing aircraft; slip/skid for fixed wing aircraft.	
					Error  For fo horizo grid m cate c actual Fly to speed Elemer ror, r Becaus to mov

B

AS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
	Lateral velocity (see remarks).  Rate vector, originating from the display center at the bottom of the viewing area, extends left or right in proportion to lateral velocity. Vector moves right for lateral velocity to the right. About 10 knots per inch. Lateral velocity for rotary wing aircraft; slip/skid for fixed wing aircraft.		
		Error from command groundspeed.  For forward speeds of 30 kts or more, horizontal elements of ground texture grid move up and down display to indicate difference between command and actual ground speed. Fly-to. Elements move down to indicate speed greater than command; vice versa. Element movement is proportionate to error, reaching max vel. at 30 kts error. Because of perspective, elements appear to move toward or away from observer.	Preceding page blank C

	VSD DISPLAYS	F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING
HOVER GROUNDSPEED	INFORMATION SYMBOLOGY				
	DESCRIPTION				
	RESPONSE SCALING				
	REMARKS				
LATERAL GROUND VELOCITY	INFORMATION SYMBOLOGY				
	DESCRIPTION				
	RESPONSE SCALING				
	REMARKS				
	INFORMATION SYMBOLOGY				
	DESCRIPTION				
	RESPONSE SCALING				
	REMARKS	A			

...WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY ...
				Status groundspeed (hover).  Horizontal elements of ground texture grid move down the display at velocity proportionate to groundspeed. Status indicator, qualitative. Not specified. For rotary wing aircraft, ground texture grid moves up or down. At zero groundspeed, grid is stationary.	Status groundspeed (hov...  For ground speeds less ... horizontal elements of ... grid move down the disp... proportionate to actual ... Status indicator. Qual... Maximum velocity of hor... 2.5 in/sec = 30 kts. At zero groundspeed, th... grid is stationary. Be... spective, elements appe... ward or away from obser...
				Lateral ground velocity.  Radial elements of ground texture grid move laterally to denote lateral velocity. At zero lateral velocity, elements are stationary. Status indicator, qualitative. Elements move opposite to motion of aircraft. Not specified.	Cross heading velocity, ...  Radial elements of groun... move laterally to denote... city. At zero lateral ... ments are stationary. Status indicator, quali... move opposite to motion... Element speed proportio... velocity; max speed 2.5...
	B				

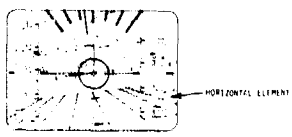
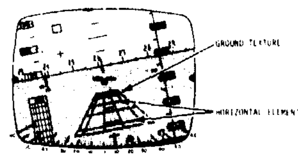
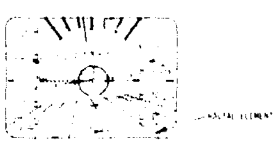
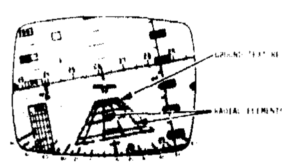
VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
	Status groundspeed (hover).  Horizontal elements of ground texture grid move down the display at velocity proportionate to groundspeed. Status indicator, qualitative. Not specified. For rotary wing aircraft, ground texture grid moves up or down. At zero groundspeed, grid is stationary.	Status groundspeed (hover).  For ground speeds less than 30 kts, horizontal elements of ground texture grid move down the display at velocity proportionate to actual ground speed. Status indicator. Qualitative. Maximum velocity of horizontal elements 2.5 in/sec = 30 kts. At zero groundspeed, the ground texture grid is stationary. Because of perspective, elements appear to move toward or away from observer.	
	Lateral ground velocity.  Radial elements of ground texture grid move laterally to denote lateral velocity. At zero lateral velocity, elements are stationary. Status indicator, qualitative. Elements move opposite to motion of aircraft. Not specified.	Cross heading velocity.  Radial elements of ground texture grid move laterally to denote lateral velocity. At zero lateral velocity, elements are stationary. Status indicator, qualitative. Elements move opposite to motion of aircraft. Element speed proportionate to lateral velocity; max speed 2.5 in/sec = 30 kts.	
			Preceding page blank C 65

TABLE 7 - SUMMARY OF VSD INFORMATION FOR EN ROUTE

	F-111B HUD	F-111B DFI	A-6A ADI	AAAIS VSD	A-7D/E HUD	ILAAS HUD	ILAAS VSD	Norden IHVD	IHAS VDI	VSTOL HUD/VSD
PITCH ANGLE	✓	✓	✓	✓	✓	✓	✓	✓	✓	
PITCH TRIM	✓	✓	✓	✓			✓			
ANGLE OF ATTACK			✓		✓	✓				
ROLL ANGLE	✓	✓	✓	✓	✓	✓	✓	✓	✓	
HEADING	✓	✓			✓		✓	✓	✓	
STEERING	✓	✓	✓	✓	✓	✓	✓	✓	✓	
TURN RATE								✓		
VERTICAL ORIENTATION	✓	✓	✓	✓	✓		✓	✓	✓	
ALTITUDE	✓	✓	✓	✓	✓		✓	✓	✓	
VERTICAL VELOCITY					✓			✓	✓	
AIRSPEED	✓	✓		✓	✓			✓	✓	
[illegible]			✓	✓	✓	✓	✓		✓	
[illegible]			✓	✓	✓					
[illegible]										
[illegible]										
[illegible]										
[illegible]				✓						
[illegible]								✓		
[illegible]										
[illegible]										
[illegible]										
[illegible]										
[illegible]									✓	
[illegible]									✓	
[illegible]								✓	✓	

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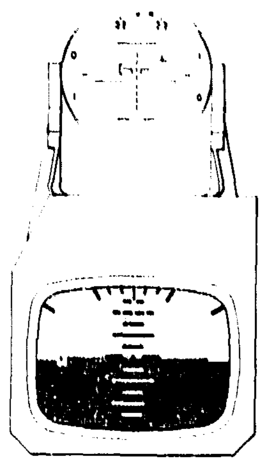
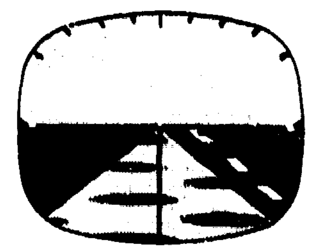
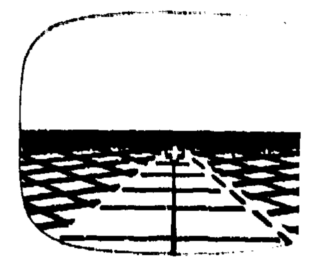
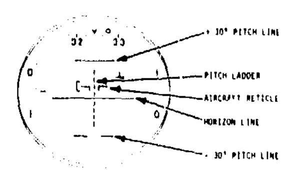
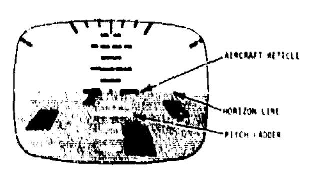
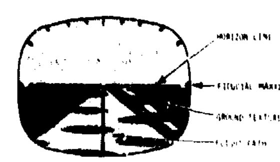
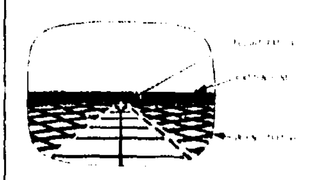
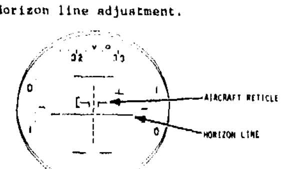
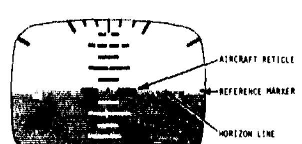
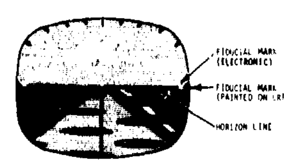
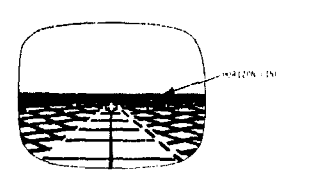
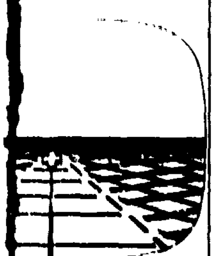
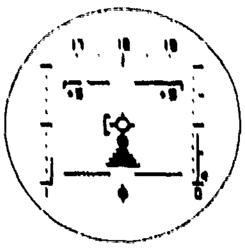
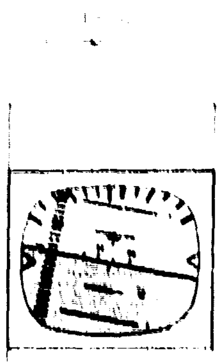
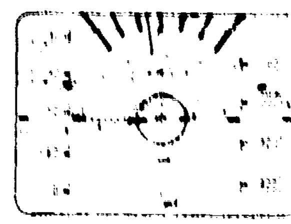
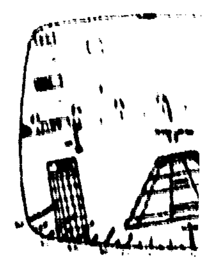
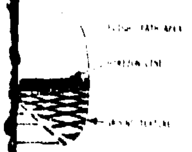
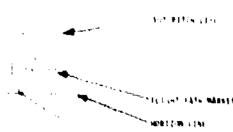
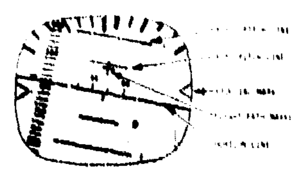
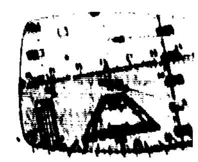
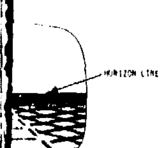
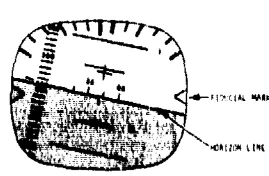
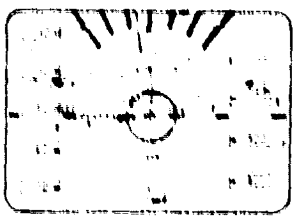
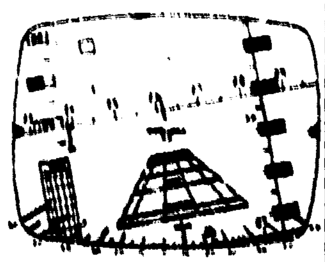
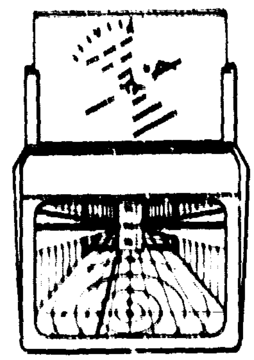
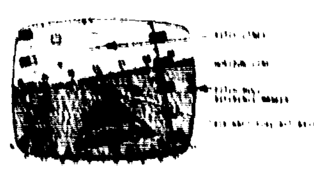
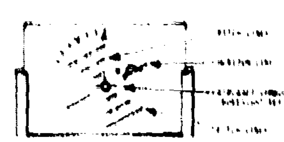
TABLE 8 - ANALYSIS OF VSDs FOR LANDING

LANDING					
VSD DISPLAYS		**F-111B** FIXED WING **HUD**	**F-111B** FIXED WING **DVI**	**A-6A** FIXED WING **ADI**	**AAAIS** FIXED WING **VSI**
PITCH ANGLE	**INFORMATION**	Pitch attitude.	Pitch attitude.	Pitch attitude.	Pitch attitude.
	SYMBOLOGY				
	DESCRIPTION	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol.	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol.	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at display center.	Horizon line moves vertically as a function of aircraft pitch angle with respect to horizontal reference plane.
	RESPONSE	Inside-out.	Inside-out.	Inside-out.	Inside-out.
	SCALING	Approximately ± 30° vertical coverage. Scale factor 1:6 (compression).	Approximately ± 30° vertical coverage. Scale factor 1.[illegible] (compression).	± 15° vertical coverage. Scale factor 1:2.5 (compression).	± 9° vertical coverage. Scale factor 1:1.
	REMARKS	Pitch ladder shows 5° increments 0 to ± 20°. Auxiliary pitch lines at + 30° (solid line) and - 30° (broken line). Nadir and Zenith not displayed.	Pitch ladder shows 10° major and 5° minor increments 0 to ± 30°. Auxiliary pitch lines, at ± 30°, ± 60° and + 90° (not shown), are color coded: black for positive, white for negative.	Auxiliary pitch lines, at ± 30°, ± 60° and ± 90° (not shown), are color coded: black for positive, white for negative.	Display center is not marked. No a[illegible] provided for quantitative reading of pitch angle.
PITCH TRIM	**INFORMATION**	Horizon line adjustment.	Horizon line adjustment.	Fiducial marker adjustment.	Horizon line adjustment.
	SYMBOLOGY				
	DESCRIPTION	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.	A manual control permits vertical adjustment of fiducial markers to compensate for differences in pitch attitude for various conditions of level flight.	A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight.
	RESPONSE				
	SCALING	Range of adjustment ± 20°.	Range of adjustment ± 15°.	Range of adjustment ± 15°.	Range of adjustment ± 6°.
	REMARKS	The local horizon is used for level flight reference.	The local horizon is used for level flight reference.		Detent in manual control used for level flight reference.

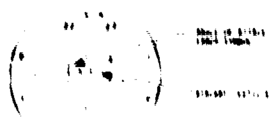
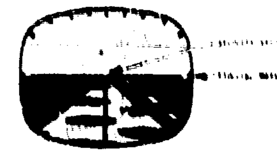
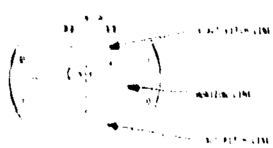
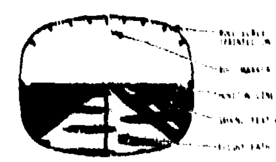
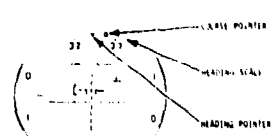
A.

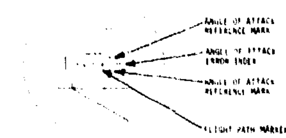
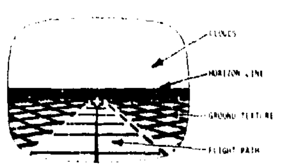
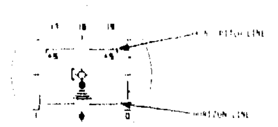
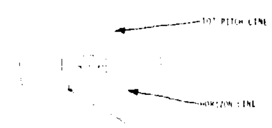
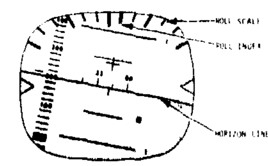
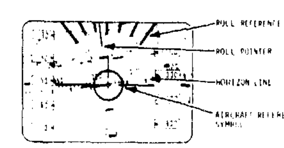
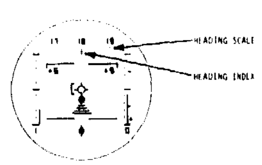
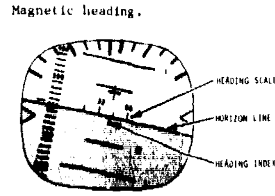
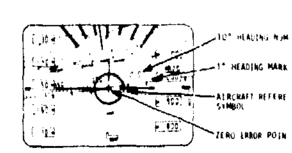
VSD (partial)	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WI…
					
	Flight path angle. 	Flight path angle. 	Pitch attitude. 	Pitch attitude. 	Pitch attitude. 
…s vertically as a func- … pitch angle with re- … ntal reference plane.	Horizon and pitch lines move vertically with respect to flight path marker to indicate flight path angle (pitch minus angle of attack). Level flight when horizon and flight path marker coincide.	Horizon and pitch lines move vertically with respect to flight path marker to indicate flight path angle (pitch minus angle of attack). Level flight when horizon and flight path marks coincide.	Horizon line and pitch line move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read from fiducial marks.	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol.	Horizon line and pitch … tically as a function … angle with respect to h… ence plane. Pitch read… roll reference mark.
	Inside-out.	Inside-out.	Inside-out.	Inside-out.	Inside-out.
…overage. Scale factor	Scale factor 1:1.	Scale factor 1:1.	Scale factor about 1:2.5 (compression).	Scale factor 1:5 (compression)	Display represents ± 2… Scale factor 1:5 (compr…
…s not marked. No scale … quantitative reading of	Auxiliary reference lines at ± 5°, ± 10° and thereafter at 5° intervals to ± 90°. Pitch angle not displayed. Flight path marker is velocity vector terminus.	Pitch scale centers on unmarked display boresight but is read at flight path marker. Pitch lines at ± 10°, ± 30°, ± 50° and ± 70°. Pitch angle not displayed. Flight path marker = velocity vector.	Pitch scale has ± 10°, ± 30°, ± 50° and ± 70° marked with 1, 3, 5 and 7 respectively; nadir, - 90°, is an open cross; zenith, + 90°, a closed cross that resembles flight director command symbol.	Pitch ladder shows ± 10°.	Pitch scale has ± 5° an… ments continuously thro…
…justment.  … permits vertical ad- … horizon line to com- … ferences in pitch atti- … conditions of level … tment ± 6°. … l control used for … ference.			Horizon line adjustment.  A manual control permits vertical adjustment of the horizon line to compensate for differences in pitch attitude for various conditions of level flight. Range of adjustment + 10° to - 20°. The local horizon is used for level flight reference.		

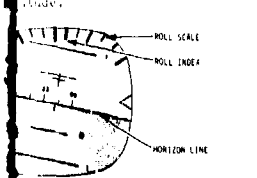
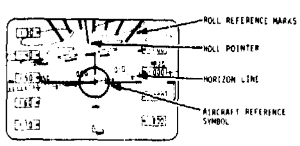
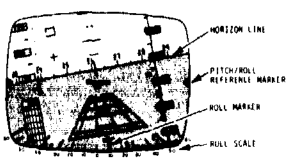
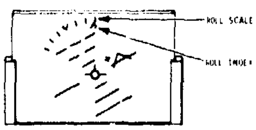
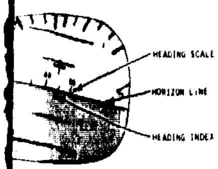
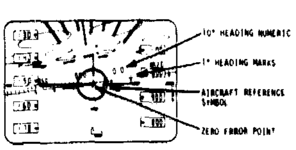
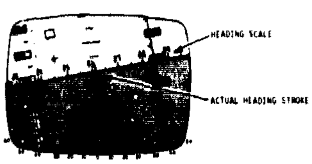
B.

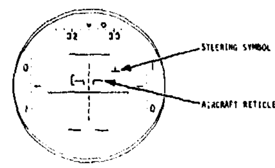
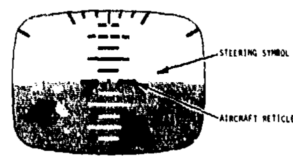
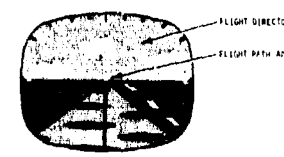
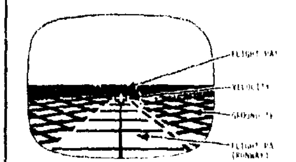
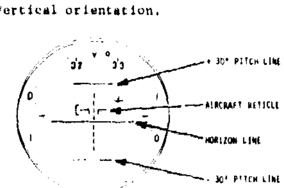
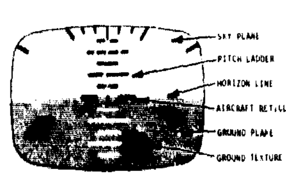
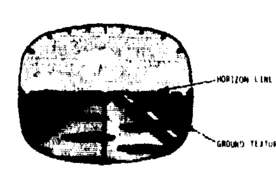
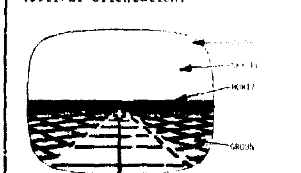
			
VSD	**Norden** ROTARY WING / FIXED WING **IEVD**	**IHAS** ROTARY WING **VDI**	**VSTOL** **HUD/VSD**
	Pitch attitude. 	Pitch attitude. 	Pitch attitude. 
...s verti- ...raft pitch ...ntal refer- ...ntal	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read at aircraft symbol.	Horizon line and pitch lines move vertically as a function of aircraft pitch angle with respect to horizontal reference plane. Pitch read from pitch and roll reference marks.	Horizon line is displaced vertically as a function of aircraft pitch, which is read at boresight reference. Auxiliary pitch reference lines are broken for pitch up attitude, solid for pitch down.
	Inside-out.	Inside-out.	Inside-out.
...compression).	Scale factor 1:5 (compression)	Display represents ± 27° of pitch. Scale factor 1:5 (compression).	Not specified.
...°, + 50° and ...nd 7 respec- ...t open cross; ...ss that re- ...nd symbol.	Pitch ladder shows ± 10°.	Pitch scale has ± 5° and ± 10° increments continuously through range.	This display format represents a concept only. Details of mechanization are not specified.
...vertical ad- ...ne to compen- ...tch attitude ...level flight. ...to - 20°. ...for level			Preceding page blank

c.

VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
ANGLE OF ATTACK	INFORMATION	Deviation from command angle of attack.	Deviation from command angle of attack.	Angle of attack.	
	SYMBOLOGY				
	DESCRIPTION	The AOA symbol is displaced vertically from the left wing of the aircraft reticle to denote AOA error. At the null position the symbol is centered about the wing of the aircraft reticle.	The AOA symbol is displaced vertically from the reference marker to denote AOA error. At the null position the symbol [illegible] reference marker.	Angle of attack shown by vertical separation of velocity vector symbol and imaginary line between fiducial markers.	
	RESPONSE	Fly-to, command.	Fly-to, command.	Inside-out, status.	
	SCALING	Scale factor 1° equals 2.5° AOA error (compression).	Scale factor 1 inch equals 2° AOA.	Scale factor 1:2.5 (compression).	
	REMARKS	The distance between the horizontal bars of the symbol represents ± 1° AOA error. The symbol blinks to denote impending stall.	The distance between the horizontal bars of the symbol represents ± 1° AOA error. The symbol blinks to denote impending stall.		
ROLL ANGLE	INFORMATION	Roll attitude.	Roll attitude.	Roll attitude.	Roll attitude.
	SYMBOLOGY				
	DESCRIPTION	Horizon line and pitch lines rotate to indicate roll.	Horizon line, pitch lines, and ground features rotate to indicate roll. Quantitative information provided by roll pointer and reference marks.	Horizon line, pitch lines, sky and ground features, and flight path rotate to indicate roll. Quantitative information provided by roll pointer and reference marks.	Horizon line, flight path, and [illegible] ground features rotate to indicate roll.
	RESPONSE	Inside-out, status.	Inside-out, status.	Inside-out, status.	Inside-out, status.
	SCALING	Scale factor 1:1.	Scale factor 1:1.	Scale factor 1:1.	Scale factor 1:1.
	REMARKS	Peripheral scales are aircraft-stabilized (do not roll). No scale marks for quantitative reading of roll angle.	Peripheral scales are earth-stabilized (roll with horizon). Roll reference marks at ± 10°, ± 20°, ± 30° and ± 60°.	Roll reference marks at 15° increments 0 to ± 60°.	No scale marks for reading of roll angle.
HEADING	INFORMATION	Magnetic heading and course.	Magnetic heading and course.		
	SYMBOLOGY				
	DESCRIPTION	Heading tape moves to indicate actual heading. Read at fixed index. Course pointer moves along scale to indicate actual course.	Heading tape moves to indicate actual heading. Read at roll pointer. Course pointer moves along scale to indicate actual course.		
	RESPONSE	Inside-out, status.	Inside-out, status.		
	SCALING	Coverage about 16°. Scale factor 1:1.2 (compression).	Coverage 75°. Scale factor 1:6 (compression).		
	REMARKS	Scale marks at 2° increments with numerals every 10°. Manually selectable on or off. A	Scale marks at 10° major and 5° minor with numerals every 30°. Heading scale is black with steering commands present and white without steering when scale is primary reference. Manual on/off.		

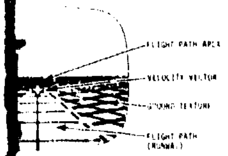
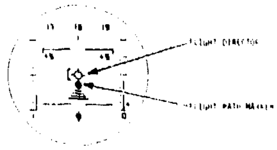
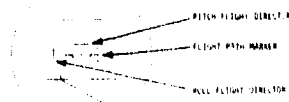
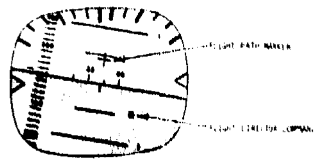
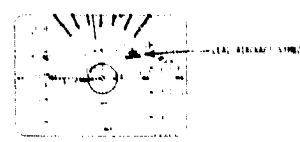
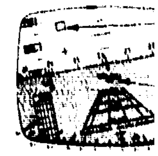
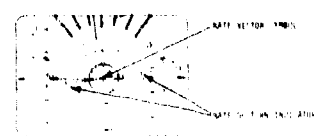
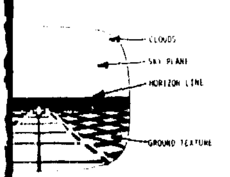
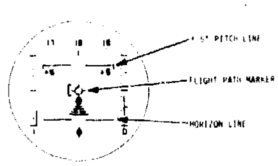
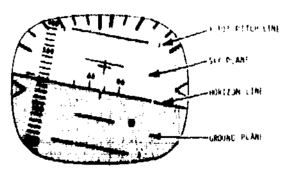
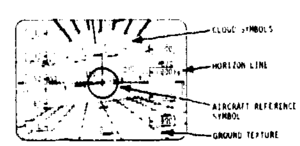
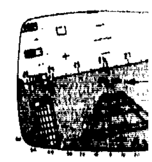
ADI	AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEV
... and ... markers,		Status angle of attack.  AOA symbol is fixed. Position of flight path marker in relation to it indicates actual AOA. Status, fly-from. Length of bracket = 2 units AOA. Center of AOA symbol represents nominal value of 17.5 units. AOA symbol blanked whenever AOA less than 12 units.	Deviation from command angle of attack.  AOA error index moves vertically with reference to the right wing of the flight path marker to indicate AOA error. AOA reference marks are fixed with respect to the flight path marker. Fly from. A high symbol indicates a + AOA error and is a command to decrease. Not specified.		
... and ... path rotate ... informa- ... ret- increments	Roll attitude.  Horizon line, flight path, and sky and ground features rotate to indicate roll. Inside-out, status. Scale factor 1:1. No scale marks for reading of roll angle.	Roll attitude.  Horizon line and pitch lines rotate to indicate roll. Inside-out, status. Scale factor 1:1. Peripheral scales are aircraft stabilized (do not roll). No scale marks for quantitative reading of roll angles.	Roll angle.  Horizon line and pitch lines rotate to indicate roll. Inside-out, status. Scaling factor 1:1. Though not specified, it is assumed that horizon and pitch lines rotate about the unmarked display center (boresight).	Roll attitude.  Horizon line and pitch lines rotate to indicate roll. Quantitative information provided by roll pointer and reference marks. Inside-out, status. Scale factor 1:1. Peripheral scales are earth stabilized (roll with horizon). Reference marks at 10° intervals, 0° to 60°.	Roll attitude.  Horizon line, pitch lines, and sky features rotate to indicate roll. Quantitative information provided by roll pointer and reference marks. Inside-out, status. Scale factor 1:1. Peripheral scales are aircraft stabi- ized (do not roll). Reverence marks at 0°, ± 10°, ± 20°, ± 30° and ± 60° roll angles.
		Magnetic heading.  Heading tape moves horizontally to indicate actual heading. Read at the fixed heading index. Inside-out, status. Scale factor 1:4.4. Heading not displayed in decluttered mode. B		Magnetic heading.  Heading tape on horizon moves to indicate actual heading. Read at fixed heading index marker. Inside-out, status. Scale factor approximately 1:2.5 (compression). Scale marks in 5° increments with numerals every 10°. Heading scale also appears on ± 30° pitch lines.	Magnetic heading.  Heading tape moves along horizon to ...dicate actual heading. Read at zer... error point (center of aircraft refe... ence symbol). Inside-out, status. 50° coverage. Scale factor 1:4 (cor... pression). Scale marks at 1° increments, with ... merals every 10°. Changes in headi... also indicated by movement and chang... in orientation of ground texture.

...S FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
...tude.  ...line and pitch lines rotate to ... roll. Quantitative information ... by roll pointer and reference ...out, status. ...actor 1:1. ...ral scales are earth stabilized ...ith horizon). Reference marks at ...ervals, 0° to 60°.	Roll attitude.  Horizon line, pitch lines, and sky features rotate to indicate roll. Quantitative information provided by roll pointer and reference marks. Inside-out, status. Scale factor 1:1. Peripheral scales are aircraft stabilized (do not roll). Reverence marks at 0°, ± 10°, ± 20°, ± 30° and ± 60° roll angles.	Roll attitude.  Horizon line and pitch lines rotate to indicate roll. Inside-out, status. Scale factor 1:1. Peripheral scales are earth stabilized (roll with horizon). Roll scale marked in 5° minor and 10° major increments.	Roll attitude.  Horizon line and pitch lines rotate to indicate roll. Quantitative information provided by fixed roll index on movable scale. Inside-out, status. Scale factor 1:1. Scale marked in 10° increments to ± 30°.
...heading.  ...tape on horizon moves to indi... ...ual heading. Read at fixed ...index marker. ...out, status. ...actor approximately 1:2.5 (com...n). ...arks in 5° increments with numer... ...ry 10°. Heading scale also ap... ...n ± 30° pitch lines.	Magnetic heading.  Heading tape moves along horizon to indicate actual heading. Read at zero error point (center of aircraft reference symbol). Inside-out, status. 50° coverage. Scale factor 1:4 (compression). Scale marks at 1° increments, with numerals every 10°. Changes in heading also indicated by movement and changes in orientation of ground texture.	Magnetic heading.  Heading tape on horizon moves to indicate actual heading. Read at intersection of actual heading stroke. Inside-out, status. Scale factor 1:5. Scale marks in 5° increments with numerals every 10°. Heading scale also appears on ± 30° pitch lines.	Preceding page blank C

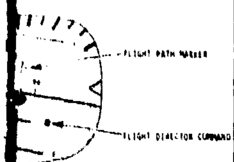
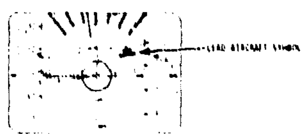
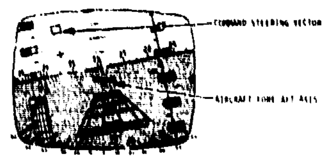
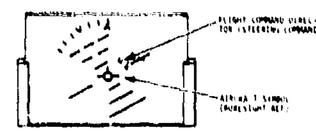
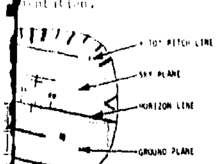
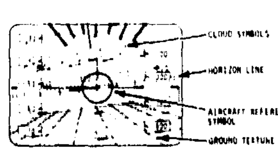
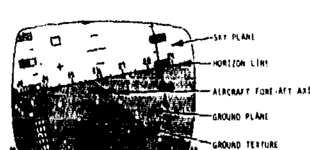
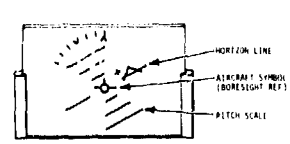
VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING V
STEERING	INFORMATION	Command heading.	Command heading.	Command pitch and roll.	Deviation from runway heading.
	SYMBOLOGY				
	DESCRIPTION	Symbol displaced from null position at aircraft reticle to indicate required changes in heading.	Symbol displaced from null position at aircraft reticle to indicate required changes in heading.	Pathway and flight director symbols displaced from null position at display center to indicate required changes in heading and/or pitch.	Lateral translation and rotation flight path symbol about apex in cates deviation from command hea
	RESPONSE	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to. Command.
	SCALING	Scale factor 1:6 (compression).	Scale factor 1:6 (compression). 1 inch = 11°.	Scale factor 1:3.3 (compression) horizontally and vertically.	Total coverage approximately ± 1 Scale factor 1:1.
	REMARKS	Simple displacement commands. Symbol limits at ± 25° of heading error. Symbol can also indicate pitch commands given such inputs.	Simple displacement commands. Symbol limits at ± 25° of heading error. Symbol can also indicate pitch commands given such inputs.	Steering commands based on displacement and rate—roll sum and pitch sum steering. Flight path apex shows direction and magnitude of required change. Flight director shows rate and error summed.	Status indication of heading cha also provided by lateral movemen ground and sky elements. The fl path terminates at 200 ft. above way.
TURN RATE	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS	Qualitative indication of turn rate provided by rate of movement of magnetic heading scale.	Qualitative indication of turn rate provided by rate of lateral movement of magnetic heading scale and ground texture.	Qualitative indication of turn rate provided by rate of lateral movement of ground texture.	Qualitative indication of turn provided by rate of lateral mo of ground texture.
VERTICAL ORIENTATION	INFORMATION	Vertical orientation.	Vertical orientation.	Vertical orientation.	Vertical orientation.
	SYMBOLOGY				
	DESCRIPTION	+ 30° pitch line is solid. - 30° pitch line is broken.	Sky and ground are differentiated by gray tone shading and by ground texture elements. Tail of steering symbol always points up; roll pointer points down.	Sky and ground are differentiated by gray tone shading, clouds, ground texture elements, and pitch line coding.	Sky and ground are differentia ground texture grid and cloud
	RESPONSE	Inside-out, status.	Inside-out, status.	Inside-out, status.	Inside-out, status.
	SCALING	N.A.	N.A.	N.A.	N.A.
	REMARKS	Vertical orientation cues not shown on display in pitch attitudes beyond ± 50°.	Major pitch lines are color coded: black for positive; white for negative pitch angles. Perspective of ground texture elements indicates direction of nearest horizon in nose-down attitude.	Perspective of ground texture elements indicates direction of nearest horizon in nose-down attitude.	Perspective of ground texture dicates direction of nearest in nose-down attitude.

A

A.

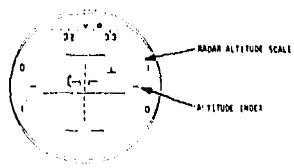
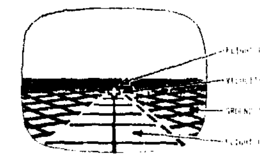
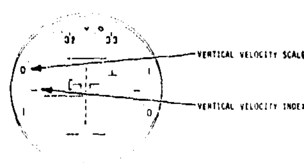
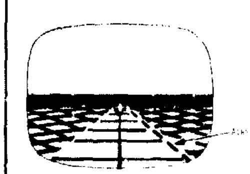
S FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROT...
...ure runway heading.	Command heading and pitch.	Command heading and pitch.	Command heading and pitch.	Command heading, pitch and roll.	Command heading and...
					
...lation and rotation of ...symbol about apex indi... ...tion from command heading.	Flight director symbol displaced from null position at flight path marker to indicate required changes in heading.	Two flight director components are driven individually from null position at flight path marker to indicate required changes in heading and/or pitch.	Two flight director components are driven individually from null position at flight path marker to indicate required changes in heading and/or pitch.	Symbol displaced from null position at display center to indicate required changes in heading, pitch, and/or roll. Can also rotate about its axis at any point to indicate bank command.	Command steering v... from null position... symbol to indic... heading and/or alt...
...ered.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, ...
...ge approximately ± 11°, ...	Not specified.	Not specified.	Not specified.	Not specified.	Not specified.
...ation of heading change ...de by lateral movement of ...e elements. The flight ...at 200 ft. above run...		"Roll" flight director commands heading change rather than roll. Both flight director components are combined into a cross (flight director symbol) when simultaneous heading and pitch commanded.	The flight director command consists of a pitch flight director symbol and a "roll" flight director symbol. The latter commands changes in heading, not roll.	Normally a zero-reader symbol, but can also be used as a predictor (future status) or rate command symbol. Can also be varied in size or shape to provide additional command cues.	In vertical direc... vector acts as an... the response to s... be a change in air... or in lift factor
				Rates of turn.	
					
				A "rate vector" symbol, originating from center of horizon, extends to left or right by an amount proportional to rate of turn. Reference marks designate 1-, 2-, & 4-min turns.	
				Status. Markings move to the right for a right turn.	
				1, 2, and 4 minute turn rates.	
...e indication of turn rate ...rate of lateral movement ...texture.	Qualitative indication of turn rate provided by rate of movement of heading scale.		Qualitative indication of turn rate provided by rate of movement of heading scale.	Rate of turn markers move independently of heading scale.	Qualitative indic... provided by rate o... of ground texture
...rientation.	Vertical orientation.		Vertical orientation.	Vertical orientation.	Vertical orientati...
					
...and ...re differentiated by ...ve grid and clouds.	Minus pitch lines are dashed and marked with negative numerals; plus pitch lines are solid and marked with numerals.		Sky and ground texture are differentiated by gray tone shading. Pitch lines are marked with numerics. Zenith and nadir are a closed and open cross respectively.	Sky and ground texture are differentiated by gray tone shading, cloud symbols and a grid pattern.	Sky and ground te... ated by gray tone... elements.
...t, status.	Inside-out, status.		Inside-out, status.	Inside-out, status.	Inside-out, statu...
	N.A.		N.A.	N.A.	N.A.
...e of ground texture grid in... ...ection of near... horizon ...own attitude.	All pitch scale numerics are earth stabilized. Hence, if they appear upside down, they indicate an inverted attitude.	B	All numerals are earth stabilized. Hence, if they appear upside down, they indicate an inverted attitude.	All numerics are earth stabilized. If they appear upside down, they indicate an inverted attitude. Ground texture perspective indicates location of nearest horizon in nose-down attitude.	All numerics are ... Ground texture gr... cates location of... nose-down attitud...

B.

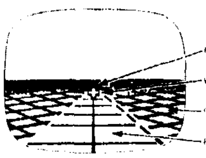
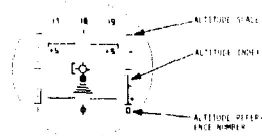
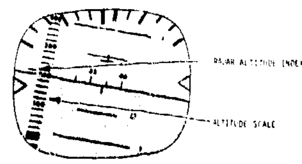
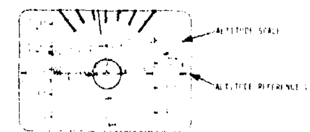
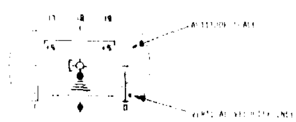
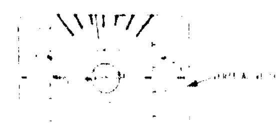
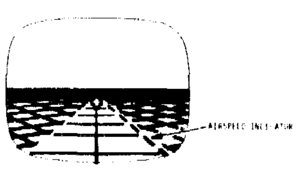
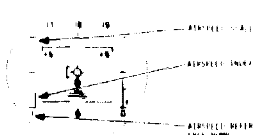
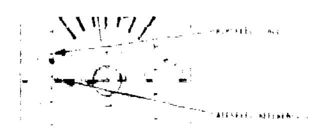
FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
...nd pitch.  ...tor components are dri... ...lly from null position at ...aircraft to indicate requir... ...heading and/or pitch.	Command heading, pitch and roll.  Symbol displaced from null position at display center to indicate requir-ed changes in heading, pitch, and/or roll. Can also rotate about its axis at any point to indicate bank command.	Command heading and altitude.  Command steering vector symbol displaced from null position at aircraft reference symbol to indicate required changes in heading and/or altitude.	Command heading and pitch.  Flight command director moves in rela-tion to fixed aircraft reference to in-dicate required changes in heading and/or pitch.
...nd, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to, command, compensatory tracking.	Fly-to.
	Not specified.	Not specified.	Not specified.
...command consists ...director symbol and ...director symbol. The ...changes in heading,	Normally a zero-reader symbol, but can also be used as a predictor (future sta-tus) or rate command symbol. Can also be varied in size or shape to provide additional command cues.	In vertical direction, command steering vector acts as an altitude command; the response to symbol displacement may be a change in aircraft pitch attitude or in lift factor (rotor blade pitch).	
	Rates of turn.  A "rate vector" symbol, originating from center of horizon, extends to left or right by an amount propor-tional to rate of turn. Reference marks designate 1-, 2-, & 4-min turns.		
	Status. Markings move to the right for a right turn.		
	1, 2, and 4 minute turn rates.		
...indication of turn rate ...rate of movement of head-	Rate of turn markers move indepen-dently of heading scale.	Qualitative indication of turn rate provided by rate of lateral movement of ground texture grid.	
...orientation.  ...and texture are differentiat-...tone shading. Pitch lines ...with numerics. Zenith and ...closed and open cross re-	Vertical orientation.  Sky and ground texture are differen-tiated by gray tone shading, cloud symbols and a grid pattern.	Vertical orientation.  Sky and ground texture are differenti-ated by gray tone shading and ground elements.	Vertical orientation.  Pitch lines indicate vertical orienta-tion. Dashed pitch lines indicate pos-itive values; solid lines negative values.
...status.	Inside-out, status.	Inside-out, status.	Inside-out, status.
	N.A.	N.A.	N.A.
...ls are earth stabilized. ...they appear upside down, they ...n inverted attitude.	All numerics are earth stabilized. If they appear upside down, they indi-cate an inverted attitude. Ground tex-ture perspective indicates location of nearest horizon in nose-down attitude.	All numerics are earth stabilized. Ground texture grid perspective indi-cates location of nearest horizon in nose-down attitude.	Preceding page blank

C

C.

VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING V
ALTITUDE	INFORMATION	Radar altitude.			Command altitude.
	SYMBOLOGY				
	DESCRIPTION	Fixed scale and moving pointer indicate radar altitude.			Size and pattern of ground textu ments vary with status altitude. formed by pathway apex varies as tion of deviation from command a
	RESPONSE	Status, pointer moves up for increased altitude.			Pilot controls altitude so that appears to be at fixed altitude
	SCALING	Scale factor 1° = 200 ft.			White ground lines on black: 1-1 over 1000 ft; black on white: 1
	REMARKS	Scale divided into 200 ft. increments 0 to 1400 ft. with numerals at 0 and 1000 ft.			Flight path terminate at 200 ft runway: pilot continues approacl touchdown under VFR conditions. texture altitude cues available touchdown.
VERTICAL VELOCITY	INFORMATION	Rate of ascent/descent.			
	SYMBOLOGY				
	DESCRIPTION	Fixed scale and moving pointer indicate vertical velocity.			
	RESPONSE	Status. Pointer moves above zero for ascent, below zero for descent.			
	SCALING	Scale factor 1° = 200 fpm.			
	REMARKS	Scale divided into 200 fpm increments with numerals at 0 and - 1000 fpm. Range + 400 fpm to - 1000 fpm.			No quantitative indication of v velocity; however, pathway disp is programmed for both altitude and command rate of change.
AIR SPEED	INFORMATION				Command airspeed.
	SYMBOLOGY				
	DESCRIPTION				Movement of dashed lines on ri flight path indicates deviatio command airspeed.
	RESPONSE				Command. Fly-to.
	SCALING				Relation of rate of movement t tude of error not specified.
	REMARKS	A			When actual airspeed equals co speed, the dashed lines are st When actual greater than comma move downward, and vice versa.

A,

...DI	AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD
	Command altitude.  Size and pattern of ground texture elements vary with status altitude. Angle formed by pathway apex varies as function of deviation from command altitude. Pilot controls altitude so that pathway appears to be at fixed altitude below. White ground lines on black: 1-100 ft & over 1000 ft; black on white: 100-1000. Flight path terminates at 200 ft above runway; pilot continues approach to touchdown under VFR conditions. Ground texture altitude cues available to touchdown.	Status and command altitude.  Altitude scale fixed. Thermometer type indexer moves on scale. The number at the scale base (*e.g.* 0) indicates the scale begins at 0 ft. Status. Not specified. 1000 ft scale structure has 100 ft increments with major marks every 250 ft. Radar or barometric altitude is displayed depending on mode. Max range not specified.		Status altitude.  Altitude tape moves against fixed reference line to provide quantitative altitude information. Status. Tape moves downward for increase in altitude. Scale factor 100 ft/in Scale has 20 feet increments with numerics every 100 ft to 5000 ft. There are 400 ft of scale in view at any one time. "Brick wall" appears at 0 ft. Scale is earth stabilized (rolls with horizon).	Altitude.  Altitude tape moves against fixed reference line to provide quantitative altitude information. Status. Tape moves downward for increased altitude. 1 raster line equals 1 foot altitude or approx. 60 feet per inch. Scale has 100 ft increments. Barometric or radar altitude not specified (either may be used).
	No quantitative indication of vertical velocity; however, pathway displacement is programmed for both altitude error and command rate of change.	Rate of ascent/descent.  Fixed scale and moving pointer indicate vertical velocity. Status. Not specified. Altitude scale also serves as vertical velocity scale.			Rate of ascent/descent.  Vertical velocity represented by bar extending from altitude reference mark. Length of bar porportional to vertical velocity. Status. Bar extends upward for ascent; downward for descent. Not specified.
	Command airspeed.  Movement of dashed lines on right of flight path indicates deviation from command airspeed. Command. Fly-to. Relation of rate of movement to magnitude of error not specified. When actual airspeed equals command airspeed, the dashed lines are stationary. When actual greater than command, lines move downward, and vice versa.	Status airspeed.  Airspeed scale fixed. Thermometer type indexer moves on scale to provide quantitative airspeed. The number at the base of the scale (*e.g.*, 1) indicates the scale begins at 100 kts. Status. Not specified. Scale has 10 knot increments with dots every 10 knots and major marks every 50 knots. Max. range not specified. Airspeed not displayed in decluttered mode.	L		Status airspeed.  Moving vertical tape read against fixed reference line indicates status airspeed. Status. Tape moves upward with increased airspeed. Not specified. Note airspeed and altitude tapes move in opposite direction for increasing values. Numerals at 10 kt intervals from - 50 to + 570 kts.

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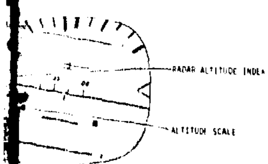
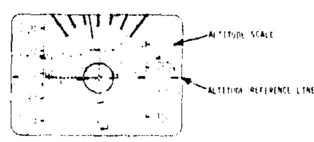
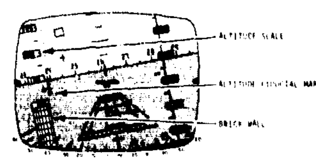
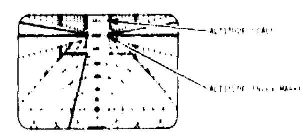
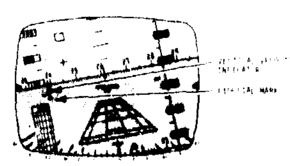
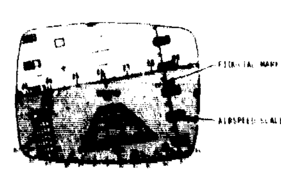
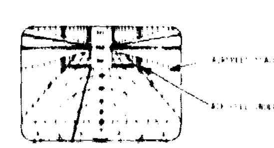
L

AS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
[illegible]titude.  [illegible] tape moves against fixed refer-[illegible] to provide quantitative alti-[illegible] [illegible] tape moves downward for in-[illegible] altitude. [illegible] 300 ft/in [illegible] feet increments with numer-[illegible] to 5000 ft. There are [illegible] scale in view at any one time. [illegible] wall" appears at 0 ft. Scale is [illegible] (rolls with horizon).	Altitude.  Altitude tape moves against fixed ref-erence line to provide quantitative altitude information. Status. Tape moves downward for in-creased altitude. 1 raster line equals 1 foot altitude or approx. 60 feet per inch. Scale has 100 ft increments. Barometric or radar altitude not specified (either may be used).	Status radar altitude.  Movable vertical tape read against fix-ed fiducial marker indicates radar al-titude. Status. Tape moves downward for in-creased altitude. 400 ft of scale in view at any one time; 50 ft increments; numerics every 100 ft. Scale not displayed above 5000 ft. "Brick wall" appears at 0 ft. Scale rolls with raster (earth stabilized).	Status altitude.  Altitude read on moving tape against fixed index. Status. Tape moves downward for in-creased altitude. 10 ft increments; numerals every 50 ft. Full range of scale not specified.
	Rate of ascent/descent.  Vertical velocity represented by bar ex-tending from altitude reference mark. Length of bar porportional to vertical velocity. Status. Bar extends upward for ascent; downward for descent. Not specified.	Rate of ascent/descent.  Vertical velocity displayed by bar em-anating from altitude fiducial marker. Length of bar proportional to vertical velocity. Status. Bar extends upward for ascent; downward for descent. Scale factor 1 in = 200 fpm. Index marks at 100 fpm increments. Range ± 400 fpm.	
	Status airspeed.  Moving vertical tape read against fixed reference line indicates status air-speed. Status. Tape moves upward with in-creased airspeed. Not specified. Note airspeed and altitude tapes move in opposite direction for increasing values. Numerals at 10 kt intervals from - 50 to + 570 kts.	Status airspeed.  Movable vertical tape read against fix-ed fiducial marker indicates airspeed. Status. Tape moves downward for in-crease in airspeed. Scale factor 10 kts/in. 5 kt scale increments with numerals ev-ery 10 kts. 40 kts of scale in view at any given time. Negative airspeed indicated by minus sign. (See also ground speed).	Status airspeed.  A speed index moves along the airspeed scale to indicate actual airspeed. In-dicated airspeed read directly from the vertical lines. Status. Moving pointer-fixed scale. Scale factor not specified. Each vertical line on airspeed scale represents a 10 kt increment. Dots are at 50 kt intervals. Sensitivity and accuracy to 1 kt or less is believed required in IFR hover.

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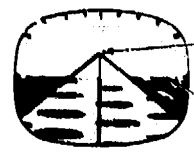
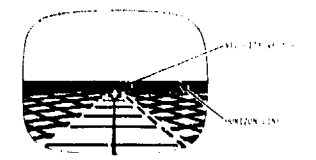
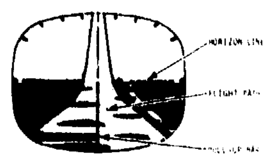
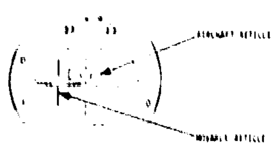
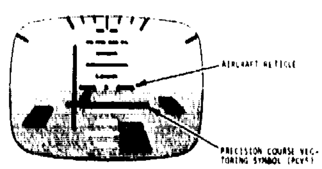
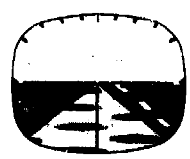
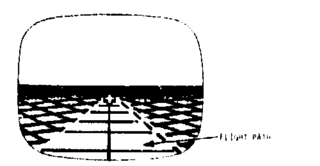
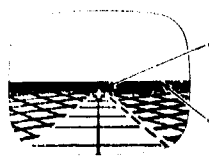
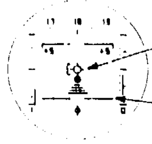
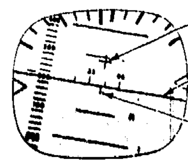
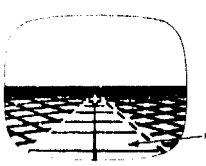
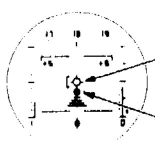
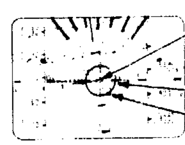
C

V&H DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
VELOCITY VECTOR	INFORMATION			Actual flight path through the airmass.	Actual flight path through the airmass.
	SYMBOLOGY				
	DESCRIPTION			The position of the velocity vector symbol with respect to the horizon line and/or the flight path apex denotes the actual flight path or velocity vector of the aircraft.	The position of the velocity vector symbol with respect to the horizon line and/or the flight path apex denotes the actual flight path or velocity vector of the aircraft.
	RESPONSE			Fly-from (velocity vector flown from present position to desired position).	Fly-from (velocity vector flown from present position to desired position).
	SCALING			Vertical scale factor 1:2.5; horizontal scale factor 1:3.3 (both compression).	Scale factor 1:1.
	REMARKS			The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.	The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.
PULL-UP	INFORMATION			Pull-up Command.	
	SYMBOLOGY				
	DESCRIPTION			Pathway apex is displaced upward sharply to command a pull-up maneuver. For a planned pull-up, a downward moving black bar serves as an anticipatory command.	
	RESPONSE			Fly-to, command.	
	SCALING			Variable.	
	REMARKS			Pull-up based on aircraft closure speed and pull-up "g" required for weapon delivery.	
GLIDESLOPE	INFORMATION	Deviation from command glideslope.	Deviation from command glideslope.	Deviation from command glideslope.	Deviation from command glideslope.
	SYMBOLOGY				
	DESCRIPTION	Vertical displacement of the movable reticle from the aircraft reticle indicates glideslope deviation. Information generated by Automatic Carrier Landing System (Data Link).	The horizontal member of the PCVS symbol moves up and down to indicate glideslope deviation. Information generated by Automatic Carrier Landing System (Data Link).	Not specified.	The flight path is driven by ILS glide slope deviation signals. It functions as a form of altitude control: too high, pathway narrows; too low, pathway widens and eventually "flips" to top of display.
	RESPONSE	Fly-to, command.	Fly-to, command.	Not specified.	Fly-to, command.
	SCALING	Not specified.	Not specified.	Not specified.	Not specified.
	REMARKS	Symbol is displayed only when Data Link message is received. The steering symbol is not shown when the movable reticle is on the display.	PCVS symbol is analogous to conventional cross pointer. Symbol is displayed only when Data Link message is received. The steering symbol is not shown when the PCVS is on the display.	A planned modification calls for glideslope to be shown by the flight path symbol. Design description not yet available. Present operational display does not have this feature.	Pilot uses bottom corners of display as reference marks to indicate the null size of the flight path. Path terminates at 200 ft. above runway.

A.

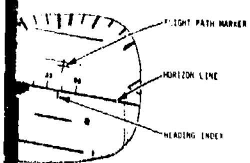
AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS
Actual flight path through the airmass.  The position of the velocity vector symbol with respect to the horizon line and/or the flight path apex denotes the actual flight path or velocity vector of the aircraft. Fly-from (velocity vector flown from present position to desired position). Scale factor 1:1. The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.	Actual flight path through the airmass.  The position of the flight path marker with respect to the horizon line denotes the actual flight path or velocity vector of the aircraft. Fly-to (fixed flight path marker flown from present position to horizon line). Not specified. In this mechanization, the flight path position represents the terminus of the aircraft velocity vector with respect to the real world.	Actual flight path through the airmass.  Flight path marker denotes actual flight path or aircraft velocity vector. Drift is its lateral displacement from center. The horizon line position in relation to it indicates aircraft flight path. Fly-to (flight path marker flown to moving horizon line). Not specified. In this mechanization, the flight path is represented by the relation between the flight path marker and horizon symbols. Neither symbol position displayed is directly related to the real world.	Actual flight path through the airmass.  The position of the flight path marker with respect to the horizon line and heading index denotes the actual flight path or velocity vector of the aircraft. Fly-from (flight path marker flown from present position to desired position). Not specified. The symbol marks the projected point of impact on the ground-sky plane if the direction and velocity of the aircraft are not changed.		Actual f  Position relation heading of aircr Fly-from Not spec During v bol will symbol d
Deviation from command glideslope.  The flight path is driven by ILS glide slope deviation signals. It functions as a form of altitude control; too high, pathway narrows; too low, pathway widens and eventually "flips" to top of display. Fly-to, command. Not specified. Pilot uses bottom corners of display as reference marks to indicate the null size of the flight path. Path terminates at 200 ft. above runway.	Deviation from command glideslope.  Vertical deviations of the flight director from the flight path marker indicate vertical displacement from the command glideslope. Fly-to, command. Not specified. Perspective lines also provide glideslope cues. In USAF version, symbol driven by flight director computer.			Deviation from command glideslope.  Vertical displacement of ILS symbol from center of aircraft reference symbol indicates glideslope deviation. Fly-to, command. Scale factor approximately 150 ft/in. Diameter of aircraft reference symbol circle equals ± 85 ft deviation. Full range of symbol movement is equivalent to ± 250 ft.	Deviati  Vertica vector vector See st

Pre

B.

AS FIXED WING VSD

flight path through the airmass.



on of the flight path marker
to the horizon line and
index denotes the actual flight
velocity vector of the aircraft.

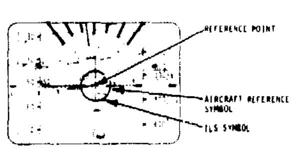
(flight path marker flown from
position to desired position).

ried.

marks the projected point of
on the ground-sky plane if the
on and velocity of the aircraft
changed.

Norden ROTARY WING FIXED WING IEVD

Deviation from command glideslope.



Vertical displacement of ILS symbol from center of aircraft reference symbol indicates glideslope deviation.

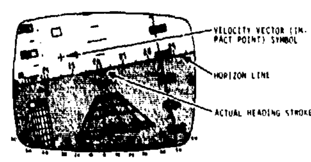
Fly-to, command.

Scale factor approximately 150 ft/in.

Diameter of aircraft reference symbol circle equals $\pm$ 85 ft deviation. Full range of symbol movement is equivalent to $\pm$ 250 ft.

IHAS ROTARY WING VDI

Actual flight path through the airmass.



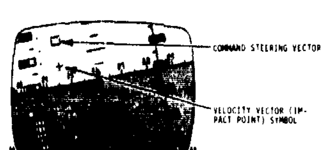
Position of velocity vector symbol in relation to horizon line and actual heading stroke indicates actual path of aircraft through the airmass.

Fly-from.

Not specified.

During vertical ascent or descent, symbol will be off display. Dynamics of symbol during hover not specified.

Deviation from command glideslope.

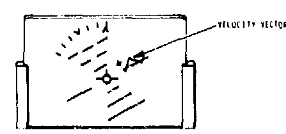


Vertical displacement of velocity vector symbol from command steering vector indicates glideslope deviation.

See steering.

VSTOL VSTOL HUD/VSD

Actual flight path through the airmass.



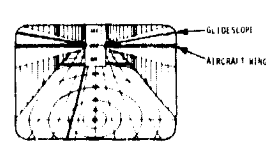
Velocity vector symbol indicates the direction of aircraft travel through the airmass.

Status.

Not specified.

Vector may be near zenith or nadir for some takeoff or landing maneuvers. Symbol would presumably be off the display in such circumstances.

Deviation from command glideslope.



Glideslope lines move against fixed representation of aircraft wings.

Fly-to, command.

Not specified.

The above information is inferred. The document describing the display is not clear on this point.

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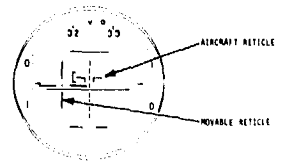
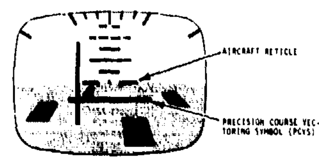
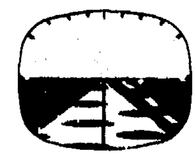
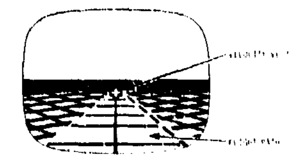
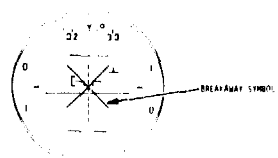
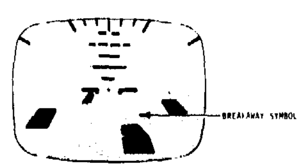
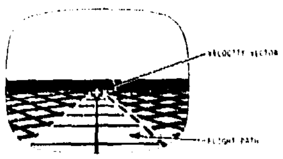
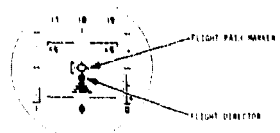
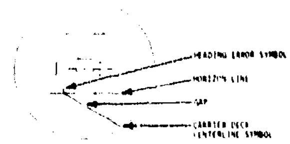
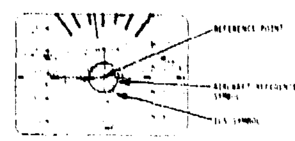
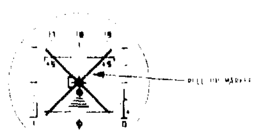
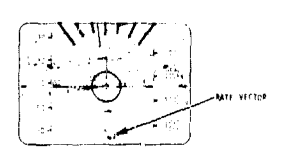
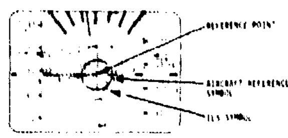
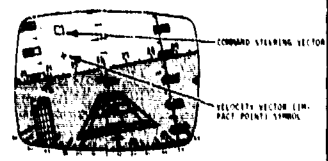
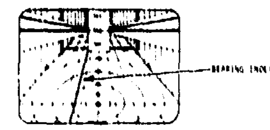
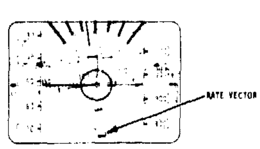
VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
GLIDEPATH	INFORMATION	Deviation from command glidepath.	Deviation from command glidepath.	Glidepath to touchdown.	Deviation from command glidepath.
	SYMBOLOGY				
	DESCRIPTION	Horizontal displacement of the movable reticle from the aircraft reticle indicates glidepath deviation. Information generated by Automatic Carrier Landing system (Data Link).	The vertical member of the PCVS symbol moves left and right to indicate glide path deviation. Information generated by Automatic Carrier Landing System (Data Link)	Not specified.	Flight path is driven by ILS localizer signals. Lateral deviation of velocit vector symbol from pathway apex: headi error. Lateral translation of pathway from display center: track error.
	RESPONSE	Fly-to, command.	Fly-to, Command.	Not specified.	Fly-to, command.
	SCALING	Not specified.	Not specified.	Not specified.	Not specified.
	REMARKS	Symbol is displayed only when Data Link message is received. The steering symbol is not shown when the movable reticle is on the display.	PCVS symbol is analogous to conventional cross pointer. Symbol is displayed only when Data Link message is received. The steering symbol is not shown when the PCVS is on the display.	A planned modification calls for glidepath to be shown by relating the flight path symbol to real world runway. Design description not yet available. This feature not on present display.	Flight path is analog of real world ru way. Pathway terminates at 200 ft abo runway.
WAVEOFF	INFORMATION	Breakaway command.	Breakaway command.		
	SYMBOLOGY				
	DESCRIPTION	A large X automatically appears at display center when aircraft exceeds landing performance envelope. Symbol blinks at 2 to 3 cps.	Large X automatically appears at display center when aircraft exceeds landing performance envelope. It blinks at 2 to 3 cps.		
	RESPONSE	Command discrete to execute a go-around.	Command discrete to execute a go-around.		
	SCALING	N.A.	N.A.		
	REMARKS	Originates with receipt of waveoff message and continues until message terminates. Also for interruption of Data Link (missed message). Used in weapon delivery to mean break off attack.	Originates with receipt of waveoff message and continues until message terminates. Also for interruption of Data Link (missed message). Used in weapon dilivery to mean break off attack.		
SIDESLIP	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS	A			

A.

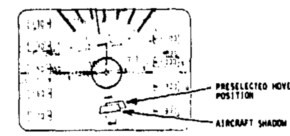
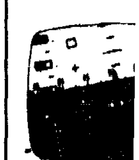
DI	AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	I
ide- ight De-	Deviation from command glidepath.  Flight path is driven by ILS localizer signals. Lateral deviation of velocity vector symbol from pathway apex: heading error. Lateral translation of pathway from display center: track error. Fly-to, command. Not specified. Flight path is analog of real world runway. Pathway terminates at 200 ft above runway.	Deviation from command glidepath.  Lateral displacement of the flight director from the flight path marker indicates lateral displacement from command glidepath. Fly-to, command. Not specified. Perspective lines also provide glidepath cues. In USAF version, symbol driven by flight director computer.	Deviation from command glidepath.  Heading error symbol on horizon line indicates relative heading to runway or carrier. Line projecting downward from horizon line denotes carrier deck centerline with gap at carrier location. Fly-to, command. Not specified. (Presumably 1:1.) Deck centerline symbol earth stabilized. Gap size proportional to angle subtended by carrier centerline 1000 ft long when viewed from a point on 3.5° glide slope. (Gap is some indication of range to go).		Deviation from command glidepath.  Lateral displacement of ILS symbol from center of aircraft reference symbol indicates glidepath deviation. Fly-to, command. Scale factor approximately 500 ft/in. Diameter of aircraft reference symbol circle equals ± 300 ft deviation. Full range of symbol movement is equivalent to ± 1500 ft.	
		Waveoff command.  Large flashing X appears at display center upon receipt of ACL waveoff message. Command descrete to execute a go-around. N.A.				
		B			Lateral velocity (see remarks).  Rate vector, originating from the display center at the bottom of the viewing area, extends left or right in proportion to lateral velocity. Vector moves right for lateral velocity to the right. About 10 knots per inch. Lateral velocity for rotary wing aircraft; slip/skid for fixed wing aircraft.	

B.

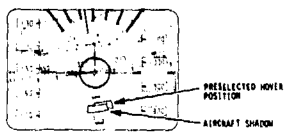
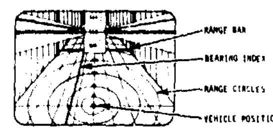
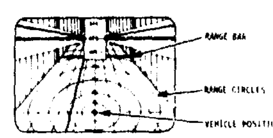
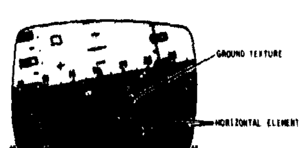
ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
	Deviation from command glidepath.  Lateral displacement of ILS symbol from center of aircraft reference symbol indicates glidepath deviation. Fly-to, command. Scale factor approximately 500 ft/in. Diameter of aircraft reference symbol circle equals ± 300 ft deviation. Full range of symbol movement is equivalent to ± 1500 ft.	Deviation from command glidepath.  Lateral displacement of velocity vector symbol from the command steering vector indicates glidepath deviation. See steering.	Bearing line from landing site.  Glidepath displayed as a bearing from the landing site. Details not specified. Fly-to. Not specified. Directional orientation of bearing line ambiguous without some heading indication. It is assumed that the aircraft position is fixed and the bearing line moves.
	Lateral velocity (see remarks).  Rate vector, originating from the display center at the bottom of the viewing area, extends left or right in proportion to lateral velocity. Vector moves right for lateral velocity to the right. About 10 knots per inch. Lateral velocity for rotary wing aircraft; slip/skid for fixed wing aircraft.		Preceding page blank

VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
HOVER POSITION	INFORMATION				
	SYMBOLOGY				
	DESCRIPTIUN				
	RESPONSE				
	SCALING				
	REMARKS				
RANGE TO GO	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS				
GROUNDSPEED	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS	A			

A.

S FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS
				Preselected hover position deviation.  Two "ground position identifiers" presented (one representing desired hover position; the other the actual aircraft position). Correct aircraft hover position is with symbols superimposed. Fly-to, command. Not specified. Ground texture not displayed with ground position identifiers. Both ground position symbols are earth stabilized.	
		B			Error from comm  For forward spe horizontal elem grid move up an cate difference actual ground Fly-to. Elemen speed greater Element moveme ror, reaching Because of per to move toward

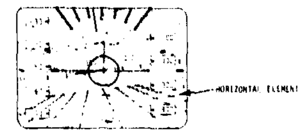
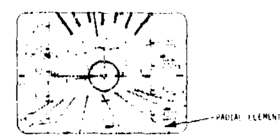
B.

VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
	Preselected hover position deviation.  Two "ground position identifiers" presented (one representing desired hover position; the other the actual aircraft position). Correct aircraft hover position is with symbols superimposed. Fly-to, command. Not specified. Ground texture not displayed with ground position identifiers. Both ground position symbols are earth stabilized.		Location of hover or landing point.  Own position is marked at the center of range circles. Range and bearing bars intersect to display hover or landing point. Not specified. (Fly-to assumed). Not specified.
			Slant range to landing or hover point.  Range to the landing site is denoted by concentric circles about the aircraft symbol. Range bar assumed to move; own position assumed fixed. Not specified. (Fly-to assumed). Not specified. (Probably variable for more sensitive control near touchdown.) It is assumed that the vehicle symbol is stationary and the range bar moves toward it.
		Error from command ground speed.  For forward speeds of 30 kts or more, horizontal elements of ground texture grid move up and down display to indicate difference between command and actual ground speed. Fly-to. Elements move down to indicate speed greater than command; vice versa. Element movement is proportional to error, reaching max vel. at 30 kts error. Because of perspective, elements appear to move toward or away from observer.	Preceding page blank C

C.

VSD DISPLAYS		F-111B FIXED WING HUD	F-111B FIXED WING DVI	A-6A FIXED WING ADI	AAAIS FIXED WING VSD
HOVER GROUNDSPEED	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS				
LATERAL GROUND VELOCITY	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS				
	INFORMATION				
	SYMBOLOGY				
	DESCRIPTION				
	RESPONSE				
	SCALING				
	REMARKS				

A.

DI	AAAIS FIXED WING VSD	A-7D/E FIXED WING HUD	ILAAS FIXED WING HUD	ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	I
					Status groundspeed (hover).  Horizontal elements of ground texture grid move down the display at velocity proportionate to groundspeed. Status indicator, qualitative. Not specified. For rotary wing aircraft, ground texture grid moves up or down. At zero groundspeed, grid is stationary.	S
					Lateral ground velocity.  Radial elements of ground texture grid move laterally to denote lateral velocity. At zero lateral velocity, elements are stationary. Status indicator, qualitative. Elements move opposite to motion of aircraft. Not specified.	

B.

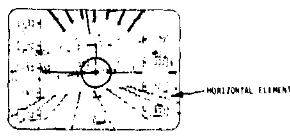
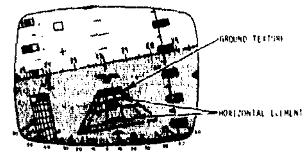
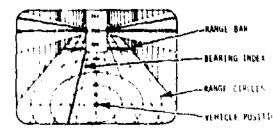
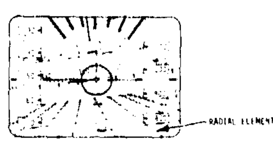
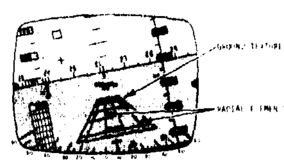
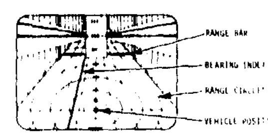
ILAAS FIXED WING VSD	Norden ROTARY WING FIXED WING IEVD	IHAS ROTARY WING VDI	VSTOL VSTOL HUD/VSD
	Status groundspeed (hover).  Horizontal elements of ground texture grid move down the display at velocity proportionate to groundspeed. Status indicator, qualitative. Not specified. For rotary wing aircraft, ground texture grid moves up or down. At zero groundspeed, grid is stationary.	Status groundspeed (hover).  For ground speeds less than 30 kts, horizontal elements of ground texture grid move down the display at velocity proportionate to actual ground speed. Status indicator. Qualitative. Maximum velocity of horizontal elements 2.5 in/sec = 30 kts. At zero groundspeed, the ground texture grid is stationary. Because of perspective, elements appear to move toward or away from observer.	Qualitative vehicle groundspeed.  Own position is marked by dot at center of concentric range circles. These are assumed fixed. Forward or reverse groundspeed is shown qualitatively by movement of range bar. Aircraft controlled to reduce range bar movement to 0 at own aircraft position. Not specified. Groundspeed display is qualitative. Quantitative display in form of scale or digital readout not specified.
	Lateral ground velocity.  Radial elements of ground texture grid move laterally to denote lateral velocity. At zero lateral velocity, elements are stationary. Status indicator, qualitative. Elements move opposite to motion of aircraft. Not specified.	Cross heading velocity.  Radial elements of ground texture grid move laterally to denote lateral velocity. At zero lateral velocity, elements are stationary. Status indicator, qualitative. Elements move opposite to motion of aircraft. Element speed proportionate to lateral velocity; max speed 2.5 in/sec = 30 kts.	Qualitative lateral movement.  Own position marked by dot in center of concentric range circles. Movable bearing index is read against fixed vehicle and range circle configuration. Aircraft controlled to keep bearing index centered on vehicle position symbol. Not specified. Quantitative display of lateral speed not specified.

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TABLE 9 - SUMMARY OF VSD INFORMATION FOR LANDINC

PITCH ANGLE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
PITCH TRIM	✓	✓	✓	✓			✓			
ANGLE OF ATTACK	✓	✓	✓		✓	✓				
ROLL ANGLE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
HEADING	✓	✓			✓		✓	✓	✓	
STEERING	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TURN RATE								✓		
VERTICAL ORIENTATION	✓	✓	✓	✓	✓		✓	✓	✓	✓
ALTITUDE	✓			✓	✓		✓	✓	✓	✓
VERTICAL VELOCITY	✓				✓			✓	✓	
AIRSPEED				✓	✓			✓	✓	✓
VELOCITY VECTOR			✓	✓	✓	✓	✓		✓	✓
PULL-UP			✓							
GLIDESLOPE	✓	✓	✓	✓	✓			✓	✓	✓
[illegible]	✓	✓	✓	✓	✓	✓		✓	✓	✓
[illegible]	✓	✓			✓					
[illegible]										
[illegible]								✓		
[illegible]										
[illegible]										
[illegible]								✓		✓
[illegible]										✓
[illegible]									✓	
[illegible]								✓	✓	✓
[illegible]								✓	✓	✓

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TABLE 10 - SUMMARY OF VSD INFORMATION CONTENT FOR ALL FLIGHT PHASES

T = TAKEOFF
E = EN ROUTE
L = LANDING

	F-111D [illegible]	F-111D [illegible]	A-7A [illegible]	AAAIS [illegible]	A-7[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	VSTOL [illegible] VSD
PITCH ANGLE	TEL	TEL	TEL	TEL	TEL	TEL	TEL	TEL	TEL	L
PITCH TRIM	TEL	TEL	TEL	TEL			TEL			
ANGLE OF ATTACK	L	L	TEL		TEL	TEL				
ROLL ANGLE	TEL	TEL	TEL	TEL	TEL	TEL	TEL	TEL	TEL	L
HEADING	TEL	TEL			TEL		TEL	TEL	TEL	
STEERING	TEL	TEL	TEL	TEL	TEL	TEL	TEL	TEL	TEL	L
TURN RATE								TEL		
VERTICAL ORIENTATION	TEL	TEL	TEL	TEL	TEL		TEL	TEL	TEL	L
ALTITUDE	TEL	TE	E	TEL	TEL		TEL	TEL	TEL	L
VERTICAL VELOCITY	T L				TEL			TEL	TEL	
AIRSPEED	E	TE		TEL	TEL			TEL	TEL	L
VELOCITY VECTOR			TEL	TEL	TEL	TEL	TEL		TEL	L
PULL-UP			EL	E	E					
GLIDESLOPE	L	L	L	L	L			L	L	L
GLIDEPATH	L	L	L	L	L	L		L	L	L
WAVEOFF	L	L			L					
PATHWAY				E						
SIDESLIP								EL		
RUNWAY HEADING [illegible]				T				T		
RUNWAY [illegible]								T		
HOVER [illegible]								L		L
[illegible]										L
[illegible]									TEL	
HOVER [illegible]								TEL	TEL	L
LATERAL GROUND VELOCITY								TEL	TEL	L

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ANALYSIS OF CONTEMPORARY HORIZONTAL SITUATION DISPLAYS

By comparison with vertical situation displays, horizontal situation displays present a considerably simpler analytic problem. Not only are there fewer examples to choose from, but they are remarkably like each other. Navigation displays consist basically of a map on which are superimposed symbols to denote present position, course, heading, and occasionally supplementary information about objectives, special landmarks, fuel range, and the like. For tactical displays the information is much the same except that a tactical situation plot is substituted for the map. There are differences among HSDs, but they tend to be largely matters of display generation, map orientation, and dynamics. With respect to information content, contemporary HSDs are nearly uniform.

A second factor which simplifies the analysis of HSDs is that they tend to be single-mode displays, at least insofar as information content is concerned. The scale of the map may be variable for purposes of mission planning, en route navigation, terminal navigation, and airfield approach. The orientation of the map may be variable so that the vertical centerline of the display lies along either a north-south line, a selected course, or present ground track. The map may be fixed or moving. But all of these have little to do with the basic information content of the display, which remains nearly constant throughout the aircraft mission.

For these reasons we have chosen a much more simple and compact analytic format. Table 11 contains illustrations of four contemporary horizontal situation displays - three navigation and one tactical. These are:

> Advanced Army Aircraft Instrumentation System (AAAIS) HSD is an advanced developmental system, not intended to be standardized for tactical operational use. Developed under U. S. Army auspices, the display has been installed in the J-50 Twin-Bonanza, the civilian counterpart of the U-8 Seminole utility aircraft, for flight test and evaluation.
>
> ITT Gilfillan Mark II HSD, officially designated the AN/ASA-61, has been developed for low altitude, high speed flight.
>
> Computing Devices of Canada Moving Map Display grew out of a concept originated by the Royal Aircraft Establishment at Farnborough and has been flight tested in England, France, and Canada. It is intended primarily as a navigational aid for low altitude, high speed aircraft using air data inputs.
>
> Hughes Aircraft Company Tactical Information Display is part of the Phoenix Missile System now under development for the F-111B aircraft. The display uses inputs from either the Phoenix computer or from Naval or Air Tactical Data Systems via Data Link.

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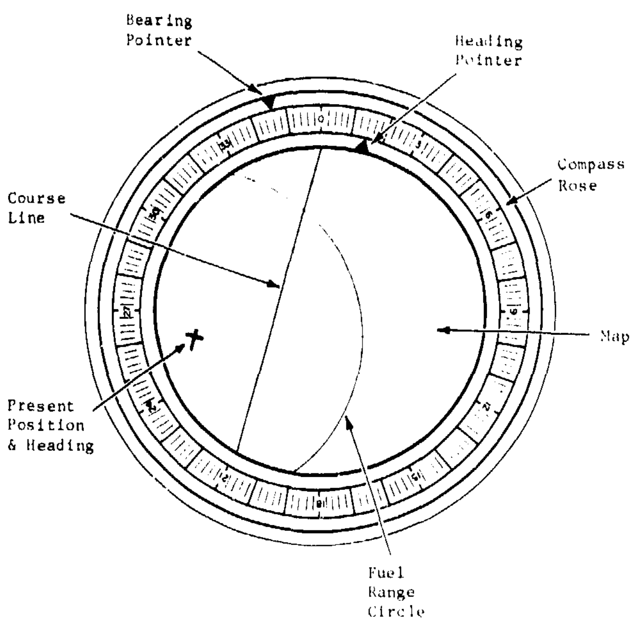
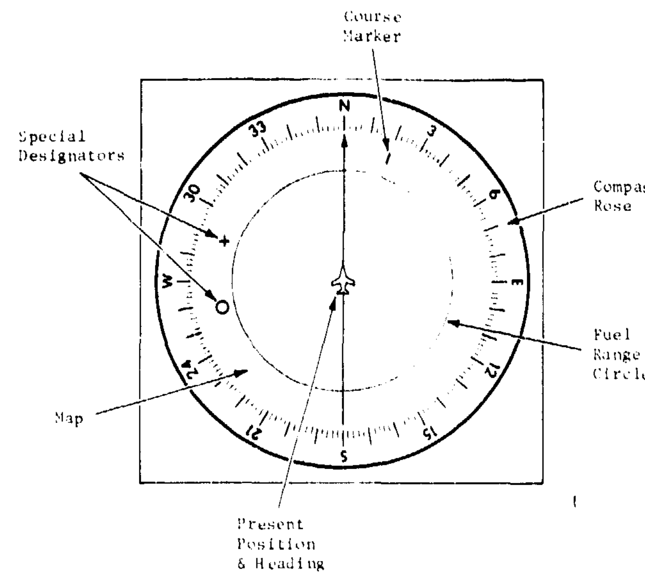
These four displays have been selected because they are representative of HSDs now under development and because they illustrate the variety of generation techniques now in use. It would have been possible to choose others or to include more examples, but this would have been unnecessarily redundant in view of the great similarity which exists among HSDs. We have not included examples of the roller map display or other devices which use a printed chart and mechanical indicators since these are not, by our definition, E/O displays.

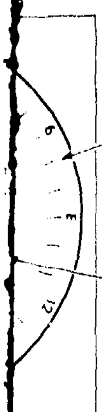
Accompanying the illustrations in Table 11 is a brief description of the type, size, method of generation, and special features of each of the displays. The information content of the displays is set forth in tabular form below the illustrations. The information items listed here are generally the same as those listed as requirements in Table 3 with two exceptions: *Fuel Range* has been added, and *Aircraft Position* has been subdivided into *Geographic Reference* and *Position Relative to Objective*.

TABLE 11 - ANALYSIS OF HORIZONTAL SITUATION DISPLAYS

ADVANCED ARMY AIRCRAFT INSTRUMENTATION SYSTEM (AAAIS)		ITT GILFILLAN MK II HSD	
 		 	
TYPE	Navigational map and radar.	TYPE	Navigational map.
SIZE	7 inch tube (6 inch usable diameter).	SIZE	Approximately 8 inches diameter.
GENERATION	CRT vidicon of 70 mm film. Sector PPI scan/radar.	GENERATION	Direct view storage tube projected in register with film chart.
FEATURES	Fixed or moving map modes. Rotatable for north or heading up. Map in shades of gray.	FEATURES	Moving map. Rotatable for north or heading up. Map in color.

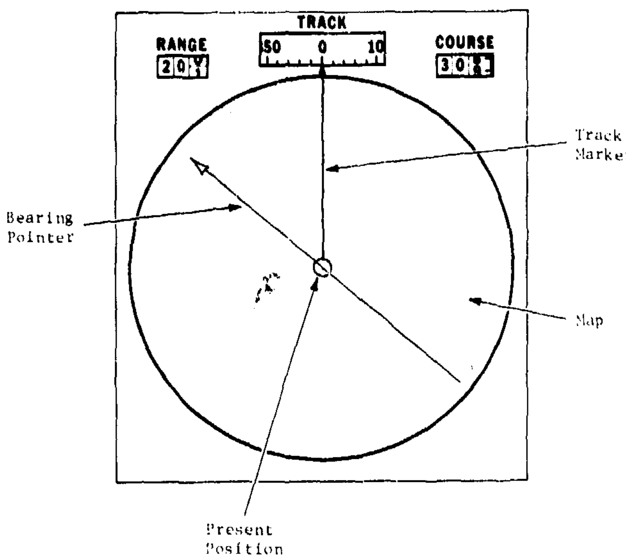
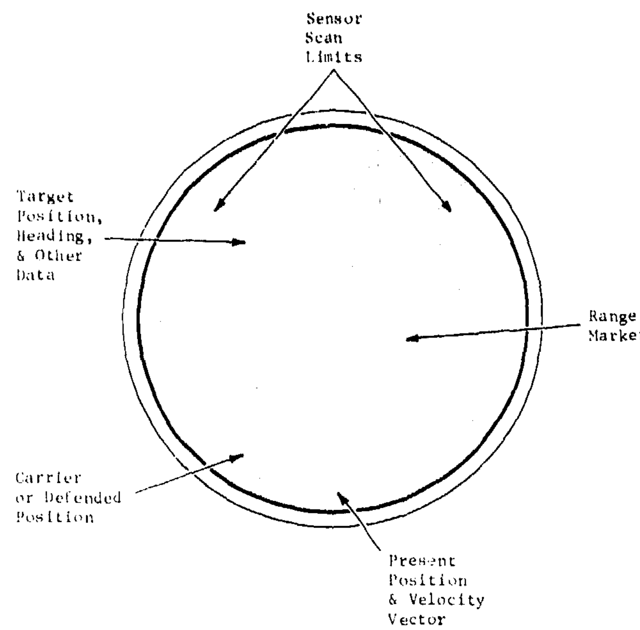
INFORMATION CONTENT	A/C Position (Geo Ref)	A/C Position (Rel to Obj)	Heading	Course	Ground Track	Range to Go	Time to Go	Fuel Quantity	Fuel Flow Rate	Gr
AAAIS	YES	YES	YES	YES	YES	YES	NO	NO	NO	BY
ITT GILFILLAN	YES	YES	YES	YES	YES	YES	NO	NO	NO	BY
CDC MOVING MAP	YES	YES	YES	YES	YES	YES	NO	NO	NO	BY
HAC TID	YES	YES	YES	NO	NO	YES	YES	NO	NO	

A



...ed in register with

...r.

COMPUTING DEVICES OF CANADA MOVING MAP DISPLAY		HUGHES AIRCRAFT COMPANY TACTICAL INFORMATION DISPLAY	
			
TYPE	Navigational map.	TYPE	Tactical situation display.
SIZE	Approximately 8 inches diameter.	SIZE	9 inches diameter.
GENERATION	Projected continuous film strip (35 or 70 mm)	GENERATION	Computer generated symbols on line-written direct view CRT.
FEATURES	Moving map; present position offsetable to periphery. Selectable for north or heading up. Map in color.	FEATURES	Present position offsetable to periphery and beyond. Selectable for north or heading up. Manual cursor for data entry and readout.

HORIZONTAL SITUATION DISPLAYS

...uel ...ntity	Fuel Flow Rate	Ground Speed	Fuel Range	Carrier Position	Dangerous Weather
NO	NO	BY INFERENCE	YES	NO	NO
NO	NO	BY INFERENCE	YES	NO	NO
NO	NO	BY INFERENCE	NO	NO	NO
NO	NO	NO	NO	YES	NO

B.

C.

SYNTHESIS OF INFORMATION REQUIREMENTS FROM STUDIES AND DISPLAYS

Table 12 combines the data from Table 3 and Table 10 to provide a direct comparison between the information requirements derived from analytic studies and the information content of contemporary vertical situation displays. Table 13 is a similar comparison of information requirements and the content of contemporary horizontal situation displays (*i.e.*, Table 3 and Table 11 combined). In several instances both sources of evidence are in close agreement, and it is a fairly easy matter to accept or reject the information item as a requirement. For several others, however, the evidence is inconclusive. These findings are as we anticipated. In part, the inconclusiveness can be attributed to our admittedly imprecise method of analysis and to the diversity of the sources from which we have drawn. Still, it is also true that disagreements between display designers and information requirements analysts do exist, and Tables 12 and 13 reflect this.

The establishment of information requirements is a complex exercise, vastly more so than would appear from what we have shown here. As we demonstrate in a later section dealing with terrain avoidance, information requirements cannot be determined in *in vacuo*. Requirements must be shaped in light of aircraft type and mission, the crew tasks, available data sensing and processing equipment, and equipment constraints. It necessitates examination of the system in all its parts and as a whole. It is an exercise that must be undertaken for each system in particular. Our purpose here, however, is more limited. We are seeking to identify those items which by common agreement or simple logic may be considered the irreducible minimum of information content for integrated flight and navigation displays. That is, we do not purport that the items resulting from our analysis represent the totality of the pilot's informational needs for all aircraft, but rather that his needs include at least these.

At the risk of seeming overcautious, we would again add the reminder that the conclusions to be drawn from this analysis are general and tentative. Not all of the items emerging from our analysis appear to us to have received their proper weight. Pull-up and velocity vector are but two examples where importance varies with the purpose for which the information is being used. For the en route situation their importance is minor at most. However, both are extremely important if the display is used for low altitude high speed flight. Caution is also called for because the information requirement studies we have sampled vary widely in their origins and methods. We cannot vouch for the pertinence, soundness, and completeness of each work. In particular, the subject of HSD information requirements does not seem to us to be as thoroughly and well handled as VSD requirements in the studies we have examined. Finally, we have almost certainly blurred some important distinctions by treating all contemporary displays as if they were alike when, in fact, they differ in rationale and purpose.

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TABLE 12 - COMPARISON OF INFORMATION REQUIREMENTS *VS*. DISPLAY CONTENT - VSDs

INFORMATION	TAKEOFF		EN ROUTE		LANDING	
	STUDIES	DISPLAYS	STUDIES	DISPLAYS	STUDIES	DISPLAYS
Pitch Angle	7/7	9/9	6/6	9/9	16/16	11/11
Pitch Trim	3/7	5/9	3/6	5/9	4/16	5/11
Angle of Attack	4/7	3/9	1/6	3/9	7/16	5/11
Roll Angle	7/7	9/9	6/6	9/9	16/16	11/11
Heading	5/7	6/9	5/6	6/9	8/16	6/11
Steering	3/7	9/9	3/6	9/9	11/16	11/11
Turn Rate	1/7	1/9	2/6	1/9	2/16	1/11
Vertical Orientation	-	8/9	-	8/9	-	10/11
Altitude	6/7	7/9	6/6	8/9	15/16	8/11
Vertical Velocity	5/7	4/9	4/6	3/9	7/16	4/11
Airspeed	7/7	5/9	5/6	6/9	15/16	6/11
Velocity Vector	2/7	6/9	2/6	6/9	6/16	8/11
Pull-up	-	-	1/6	3/9	1/16	1/11
Glideslope	NA	NA	NA	NA	9/16	9/11
Glidepath	NA	NA	NA	NA	9/16	10/11
Waveoff	NA	NA	NA	NA	2/16	3/11
Pathway	-	-	-	1/9	-	-
Sideslip	1/7	-	2/6	1/9	1/16	1/11
Runway Heading Error	-	2/9	NA	NA	2/16	-
Runway Distance	1/7	1/9	NA	NA	2/16	-
Hover Position	-	NA	-	NA	-	3/11
Range to Go	-	-	2/6	-	7/16	1/11
Groundspeed	1/7	2/9	3/6	1/9	4/16	1/11
Hover Groundspeed	-	2/9	-	2/9	-	3/11
Lateral Ground Velocity	-	2/9	-	2/9	-	3/11

All figures are ratios of the number of times listed to the total number of studies or displays considered for each flight phase. A dash (-) indicates the item is not listed as a requirement or not displayed. NA indicates not applicable.

TABLE 13 - COMPARISON OF INFORMATION REQUIREMENTS *VS.* DISPLAY CONTENT - HSDs

INFORMATION	STUDIES	DISPLAYS
A/C Position (Geo. Ref.)	3/16	4/4
A/C Position (Rel. to Obj.)	3/16	4/4
Heading	9/16	4/4
Course	1/16	3/4
Ground Track	2/16	3/4
Range to Go	7/16	4/4
Time to Go	2/16	1/4
Fuel Quantity	6/16	-
Fuel Flow Rate	6/16	-
Groundspeed	5/16	3/4
Fuel Range	-	2/4
Carrier Position	4/16	1/4
Dangerous Weather	2/16	-

All figures are ratios of the number of times listed to the toal number of studies or displays considered. A dash (-) indicates the item is not listed as a requirement or not displayed.

We do not believe these deficiencies will detract seriously from the presentation of a valid broad-spectrum picture of the current state of E/O displays. Our concern, which is the reason for repeated caveats, is that readers who are less familiar with the source materials may inadvertently generalize beyond our intent. Therefore, our final summary contains not only an estimate of what the assembled data indicate but also interpretive commentary, based on our own experience, to correct any imbalances and omissions that may have resulted from the analytic method we have used.

Summary of VSD Information Requirements

The following is a listing of the items identified through our analysis as possible information requirements for vertical situation displays. They are listed approximately in order of importance and rated according to a four point scale: Mandatory, Desirable, Optional, Not Required. A brief commentary is added for each to explain the requirement and justify the rating given. A tabular summary of these requirements is provided in Table 14 at the end of this section.

It should be noted that the list identifies only the kind of information required. No distinction is made on the basis of the form of the information (*i.e.*, qualitative *vs.* quantitative), the source (*e.g.*, pressure or radar altitude), the degree to which it is processed (*e.g.*, indicated *vs.* true airspeed or mach number), or the manner of presentation (*e.g.*, status *vs.* command *vs.* error). In cases where these distinctions may be important, explanation is included in the commentary.

> <u>Roll and Pitch Angle</u> (Mandatory for all flight phases) - There is unanimous agreement among analysts and display designers on these items, whose importance is obvious. In addition to qualitative roll and pitch information, quantitative indication is needed for some aircraft and certain maneuvers, *e.g.*, pitch angle control for weapon delivery or specific roll angles for procedural turns. In general, the need for quantitative information will be determined by aircraft type and mission and anticipated operational procedures.
>
> <u>Vertical Orientation</u> (Mandatory for all flight phases) - The rating is based on the emphasis given to this item in current displays. It is not specifically called out in the analytic studies, perhaps because it may be considered implicit in the presentation of roll and pitch attitude. We prefer to stress it by calling it out separately. It is especially important in view of the use of E/O displays in all-weather and night situations.

Altitude (Mandatory for all flight phases) - While there is general agreement on the importance of altitude information, some difference of opinion exists as to whether radar or barometric sources should be used at low altitudes (*i.e.*, at less than 5000 feet above terrain). There is also disagreement on whether the presentation of altitude should be as status, command, or both. A resolution of these issues can usually be reached by examination of the aircraft mission and the anticipated conditions of operational use. Altitude information, in some form, should be considered an essential ingredient of integrated flight displays.

Airspeed (Mandatory for all flight phases) - Nearly all the analytic studies list airspeed as a requirement, but only about half of the displays examined here actually present this information. The importance of this item seems intuitively obvious, and we have listed it as mandatory for all flight phases. As with altitude, the choice of command or status presentation will depend upon the mission and the anticipated operational conditions. These considerations and the kind of data processing equipment available will also determine whether the information is to be displayed as indicated airspeed, true airspeed, or mach number.

Steering (Mandatory for all flight phases) - All contemporary displays present some form of steering information for all flight phases. The analytic studies show considerably less unanimity except for landing where 11 of 16 reports list steering as a requirement. Our rating has been guided by the emphasis placed on steering by the display designers and by our own view that steering is of critical importance in an integrated flight display. In most cases steering is presented on contemporary displays as command information relating to the horizontal component of the aircraft flight path. In a few cases the vertical component is presented as well. In specifying steering as a requirement here, no preference is implied. The question is, however, of great importance; and it will be taken up, along with the related topic of quickening, in the next chapter in a discussion of display dynamics.

Glideslope and Glidepath (Mandatory for landing) - This is actually a form of steering information, where glideslope refers to the vertical component of the flight path with respect to the landing site and glidepath refers to the horizontal component. The form of the information and the nature of the presentation are partly dependent on the kind of on-board or external guidance system available. There is strong but not unanimous agreement among the studies and display designers on the need for this information for landing.

Angle of Attack (Mandatory for landing, desirable or optional for takeoff) - The rating of this requirement is subject to qualification. Less than half of the studies and the displays examined here consider it a requirement for landing. Fewer still list it as a requirement for takeoff. We specify it as a mandatory item for landing with the condition that it applies primarily to jet aircraft for carrier landings and short-field landings (with or without arrestment). For takeoff and other uses the rating depends upon the importance of angle of attack information in controlling the particular aircraft.

Hover Position (Mandatory for landing, optional for takeoff) - This requirement applies to rotary-wing and V/STOL aircraft only. Hover position is not cited as a requirement in the studies we have examined, but - as noted earlier - there is a heavy fixed-wing bias in the documents sampled. The three displays which are designed for helicopters or V/STOL aircraft all present hover position for landing. This information, which is somewhat like glideslope and glidepath information for fixed-wing aircraft, is therefore given mandatory status for rotary wing and V/STOL aircraft for landing. Hover position seems to have lesser importance for takeoff, but it has sufficient value to merit listing it as an optional item for display.

Hover Groundspeed (Mandatory for landing, optional for takeoff) - The requirement applies to rotary-wing and V/STOL aircraft only. The rationale is like that for hover position.

Lateral Ground Velocity (Mandatory for landing, optional for takeoff) - The requirement applies to rotary-wing and V/STOL aircraft only. The rationale is like that for hover position.

Pitch Trim (Desirable for en route and landing, optional for takeoff) - Roughly half of the studies and displays cite pitch trim information as a requirement. For displays which are not flight path centered, it is probably more important than the data indicate, since it affords a convenient and simple way of using the display horizon line as a level flight reference during cruise at varying conditions of pitch trim. Support for this contention can be found in the fact that conventional electro-mechanical attitude indicators customarily have a pitch trim adjustment feature. A problem with pitch trim adjustment is that the pilot must remember to remove the correction factor by resetting the display to obtain true attitude reference for landing.

Vertical Velocity (Desirable for all flight phases) - The evidence from the studies and displays does not conclusively support this as a requirement. The rating reflects our own view that vertical velocity information is extremely useful during climbout for monitoring climb schedule and anticipating level-off at cruise

altitude. Apart from its use en route whenever altitude changes must be made, vertical velocity information is valuable for altitude holding since it is a more sensitive index of performance than altitude alone. It is of particular importance for descent from altitude, approach, and landing, where it may even deserve mandatory status.

Velocity Vector (Desirable for en route and landing, optional for takeoff) - This is a controversial item since its importance is partially dependent upon whether the display is centered vertically about the flight path or the aircraft pitch axis. For flight-path centered displays, velocity vector information is mandatory; for pitch displays it is less important although obviously still useful as an indicator of aircraft performance in the vertical situation plane. Our rating of desirable is tentative.

Heading (Desirable for all flight phases) - This item should not be confused with steering. Heading refers to a status indication of the direction of the longitudinal axis with respect to north (either true or magnetic); steering implies a command indication. The importance of heading will vary somewhat with the quality of steering information available and with the need for north reference on the VSD during the mission. If there is also a horizontal situation display in the cockpit, the importance of heading on the VSD may diminish. That is, heading is more appropriate and valuable on the HSD, where it is integrated with other related elements of aircraft performance (course, ground track, drift, etc.). On the VSD it is somewhat isolated and less useful except in circumstances where the pilot must hold a certain heading or where steering commands are given in the form of heading, such as in a ground controlled approach.

Turn Rate (Desirable for landing, optional for en route) - The need for this information has received scant support in the studies and displays examined here. The rating is based partly on our own view of the usefulness of turn rate in approach and landing for making procedural turns under air traffic control. It should be noted that some contemporary VSDs do not contain turn and sideslip information as an integral part of the display but present it, instead, on the conventional "needle-ball" instrument mounted in proximity to the display.

Sideslip (Optional for en route and landing) - The need for this information is not well supported in the studies and displays. However, see the remark under Turn Rate above.

Waveoff (Optional for landing) - This is an optional item applicable only to carrier-based aircraft operating under the Automatic Carrier Landing system or similar external control via data link.

Pull-up (Optional for en route and landing) - This is an optional item for most aircraft. However, if the mission of the aircraft entails terrain avoidance or terrain following, it becomes a mandatory requirement.

Range to Go (Optional for en route and landing) - This is more properly an HSD information requirement. However, for certain tactical applications it may be useful to present range information in combination with a display of the vertical situation. It may also be useful for landing, providing there is suitably accurate range sensing equipment.

Runway Heading Error (Not required) - This item is presented on only two displays for takeoff, and it is mentioned in two reports as a landing requirement. These are insufficient grounds to justify making it a VSD requirement. In the case of landing it appears to be synonymous with glidepath, and as such it is covered above.

Runway Distance (Not required) - There is virtually no support for this as a takeoff requirement; it is mentioned in only one report and presented on only one display. For landing it appears to be the same information as Range to Go which is discussed above.

Groundspeed (Not required) - For fixed wing aircraft this appears to be a requirement more appropriate for HSDs than for VSDs. As a requirement for rotary-wing and V/STOL aircraft it is discussed under Hover Groundspeed above.

Pathway (Not required) - This item is contained on only one display, where it serves an an indication of course and ground track. It seems more appropriate to display this information on an HSD in conjunction with other elements of the horizontal situation.

TABLE 14 - COMPOSITE TABLE OF VSD INFORMATION REQUIREMENTS

INFORMATION REQUIREMENT	RATING*			COMMENTS
	T	E	L	
Pitch Angle	1	1	1	Unanimous agreement
Roll Angle	1	1	1	Unanimous agreement
Vertical Orientation	1	1	1	Rating based on emphasis given in current displays
Altitude	1	1	1	Nearly unanimous agreement
Airspeed	1	1	1	Nearly unanimous agreement
Steering	1	1	1	Rating based on emphasis given in current displays
Glideslope	0	0	1	Nearly unanimous agreement for landing
Glidepath	0	0	1	Nearly unanimous agreement for landing
Angle of Attack	2/3	0	1	Especially important for carrier landing; importance for takeoff depends on aircraft
Hover Position	3	0	1	Required only for rotary wing and V/STOL
Hover Groundspeed	3	0	1	Required only for rotary wing and V/STOL
Lateral Ground Velocity	3	0	1	Required only for rotary wing and V/STOL
Pitch Trim	3	2	2	Evidence not conclusive; probably more important than data indicate
Vertical Velocity	2	2	2	Evidence not conclusive; probably more important than data indicate, especially for landing
Velocity Vector	3	2	2	Controversial item; ratings tentative
Heading	2	2	2	Importance based on quality of steering and availability of same information on HSD
Turn Rate	0	3	2	Our opinion; not fully supported by data
Sideslip	0	3	3	Need not well supported
Waveoff	0	0	3	Need not well supported
Pull-up	0	3	3	Mandatory if display used for low altitude high speed missions
Range to Go	0	3	3	More important as HSD requirement
Runway Heading Error	0	0	0	Not a requirement
Runway Distance	0	0	0	Not a requirement
Groundspeed	0	0	0	Not a VSD requirement; see HSD
Pathway	0	0	0	Not a VSD requirement; see HSD-Course

* 1 = Mandatory 2 = Desirable 3 = Optional 0 = Not Required

Summary of HSD Information Requirements

The following is a listing and brief discussion of the items identified by our analysis as information requirements for horizontal situation displays. They are arranged roughly in order of importance and rated on a four point scale: Mandatory, Desirable, Optional, Not Required. These requirements are summarized in Table 15 at the end of this section.

Aircraft Position - Geographic Reference (Mandatory) - All four of the displays analyzed provide this information, which is basic to any navigational display. The studies, on the other hand, appear to be considerably less emphatic about the need for positional information. In part, this may be attributable to the fact that the studies are more concerned with VSDs than HSDs. Our view is that the evidence from contemporary displays, and simple logic, dictate making this a mandatory item.

Aircraft Position - Relative to Objective (Mandatory) - This item, too, is emphasized more in current displays than in the studies. The mandatory rating is based on the obvious importance of this information and on the weight of current practice in display design.

Heading (Mandatory) - All the displays and a majority of the studies indicate that heading is a requirement for horizontal situation displays. As noted in the previous section, heading is also a VSD information requirement, although it is less important on the VSD than on the HSD where it is integrated with the other essential elements of the horizontal situation.

Course (Mandatory) - This item refers to the desired path of the aircraft over the ground; and, as such, it is command information. Course is considered mandatory for navigation displays. It is not necessarily so for tactical displays, especially for intercept, where the air situation is more important than the disposition of targets in relation to the ground.

Ground Track (Mandatory) - Ground track refers to the actual path or track which the aircraft makes over the ground. It should not be confused with course, which is command or intended path. The interplay of ground track with course and heading provides the pilot with an index of aircraft performance in the horizontal situation and with derivative information such as drift. These three elements and aircraft position thus constitute the basic elements of the horizontal situation display.

Range to Go (Mandatory) - The displays and studies agree on the importance of range information. It is not clear, however,

whether this requirement is satisfied by a presentation of the geometric relation between present position and the objective or whether a more discrete and quantitative statement is called for. We prefer to state the requirement generally and let the specific form in which the information is presented be decided on the basis of the mission of the particular aircraft and the importance of range information in carrying out that mission.

Fuel Quantity and Flow Rate (Desirable) - Several of the information requirement studies cite these items as necessary for navigation. However, none of the four displays present this information, as such; they show fuel range instead. In many ways, fuel range is the more useful since it is an integration of fuel quantity, flow rate, and groundspeed into a form which is more readily understandable in the coordinates of the horizontal situation. However, if the display system does not include equipment to make this computation, the pilot must do it for himself, and fuel quantity and flow rate should be displayed in some way. We list these items as requirements only on the condition that the display system cannot provide an indication of fuel range.

Groundspeed (Desirable) - There is substantial but not full agreement between the studies and the displays on this requirement. In part, its value lies in its use for computing fuel range, and its importance may diminish somewhat if fuel range is presented on the display as a separate item. However, groundspeed is also needed to estimate time to the objective or a navigational check point; and, therefore, it seems to merit listing as a desirable item for the HSD.

Fuel Range (Desirable) - As indicated above, fuel range is a more usable, and hence desirable, parameter for display than its components. Of the four HSDs analyzed here, the three which are navigational displays all present fuel range. This has dictated our rating and our preference for fuel range over a display of fuel quantity and flow rate as separate quantities.

Time to Go (Optional) - Only two studies and one display contain time to go as a requirement. However, its importance may be greater than indicated, especially if the aircraft mission involves time-critical activities. We list it as an optional item but recognize that it may have greater importance in some applications.

Carrier Position (Optional) - For carrier-based aircraft this information would be an aid for navigation and fleet air defense. Because of carrier mobility and the length of some aircraft missions, the carrier position fix must be regularly up-dated by an on-board

computer or by external tactical data systems via data link.

Dangerous Weather (Desirable/Optional) - This item is mentioned in two studies, but it is not contained on any of the HSDs we have considered. The value of weather information, especially for long distance flights and operation in terminal areas, is obvious. Weather information has not been incorporated in present HSDs probably because of the technological difficulty and expense of combining a weather radar display with cartographic information. We list this item as desirable because of its unquestionable importance and optional because of present technological limitations.

TABLE 15 - COMPOSITE TABLE OF HSD INFORMATION REQUIREMENTS

INFORMATION REQUIREMENT	RATING*	COMMENTS
A/C Position (Geo. Ref.)	1	Rating based on emphasis given in current displays; may not be mandatory for some tactical displays
A/C Position (Rel. to Obj.)	1	Rating based on emphasis given in current displays
Heading	1	Also a VSD requirement, but more important on HSD
Course	1	Mandatory for navigation displays; not necessarily so for tactical displays
Ground Track	1	Refers to path made good not to command path, which is course
Range to Go	1	Nearly unanimous agreement
Fuel Quantity	2	Not necessary if fuel range displayed
Fuel flow rate	2	Not necessary if fuel range displayed
Groundspeed	2	Not full agreement but seems important for navigation
Fuel range	2	Integration of fuel quantity, flow rate, airspeed, and wind; rating based on emphasis given in current displays
Time to Go	3	May be more important if aircraft mission involves time-critical activities
Carrier position	3	Value depends on availability of updated information of carrier position
Dangerous weather	2/3	Technologically difficult now

* 1 = mandatory 2 = Desirable 3 = Optional 0 = Not required

TERRAIN AVOIDANCE

Terrain avoidance is the most exacting of the low altitude flying techniques for fixed wing aircraft. It makes great demands on pilot skill and, because of the severe penalties for error, places him under great psychological stress. Terrain avoidance requires that the pilot simultaneously maintain close control of altitude above terrain, manage g-factor stresses, and make precise heading changes so that hilltops may be flown over or around. This latter control function distinguishes terrain avoidance from *terrain following*, in which the aircraft flies a more or less straight flight path laterally without making heading changes to maneuver around terrain obstacles. Terrain avoidance and terrain following are similar in that they entail flying a low altitude profile which parallels the terrain contour. Both are to be distinguished from the less demanding *terrain clearance*, which merely calls for the aircraft to establish and maintain a minimum safe clearance altitude above the highest obstacle along the flight path.

In this section we will deal primarily with terrain avoidance since it is the most rigorous of the three low altitude regimes and poses the most serious problems for the display designer. However, much of what we say will also apply to terrain following, which may be thought of as just the vertical component of the terrain avoidance maneuver. Terrain clearance will be mentioned only in passing.

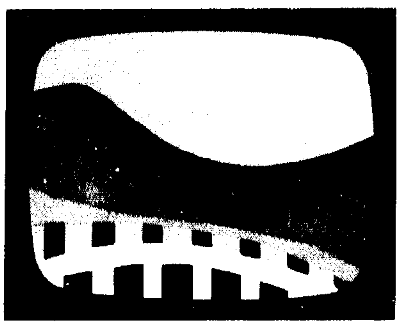


Figure 3
TERRAIN AVOIDANCE DISPLAY

C-scan (Azimuth-Elevation). Range to terrain is shade-coded. Key ranges (*e.g.* 1/4 and 1 mile) are highlighted by vertical bars.

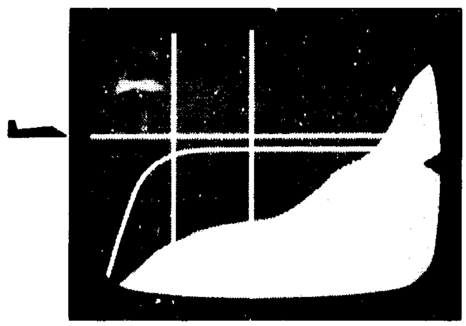


Figure 4
TERRAIN FOLLOWING DISPLAY

E-scan (Range-Elevation). A flight line, two range lines, and a constant altitude line (curved) are also shown.

(Adapted from Kaiser Aerospace and Electronics data)

Figures 3 and 4 show two display formats which may be used for low altitude flight. Both are head-down raster type displays. However, it is also possible to use a head-up display for terrain avoidance and terrain following. Naish (1961) and Lambert (1964) have reported successful flight tests at low altitude with a head-up display. More recently, Soliday and Milligan (1967) completed extensive simulation studies of terrain avoidance capability with the Sperry and North American head-up displays. At present, however, the only terrain avoidance display in operational use in U.S. aircraft is that of the A-6A, which is a head-down vertical situation display. For comparison, the "pole track" display developed by the SAAB Aircraft Company and the Sperry head-up display are illustrated below in Figures 5 and 6 . The SAAB display was designed primarily for low altitude flight and landing and seems to be highly specialized for such purposes. Full details on performance and intended usage were not available in English, although there is ample documentation in Swedish.

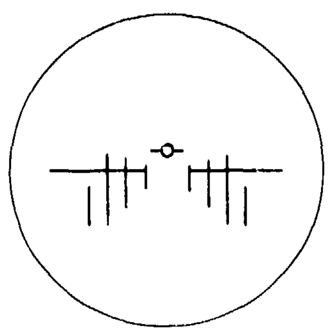


Figure 5 SAAB POLE TRACK DISPLAY

-O- shows actual flight path relative to horizon. Vertical poles stand on the ground with upper ends at desired altitude. Short outer poles are an arbitrary unit of altitude reference. Example shows aircraft below desired flight path and climbing. Altitude is 1 1/2 units.

(Adapted from Nordstrom 1965)

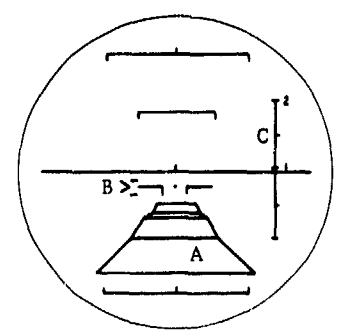


Figure 6 SPERRY HEAD-UP DISPLAY

In addition to conventional horizon and pitch lines, the display shows a terrain carpet (A), airspeed index (B), and radar altitude scale (C).

(Adapted from Soliday and Milligan, 1967)

The preceeding illustrations are not meant to suggest that information requirements for low-level flight are confined to data about the vertical situation. Information about the vertical situation may be the most compelling, but other information is also of significant interest. For example, the importance of continual geographic orientation and navigational reference has recently been stressed by McGrath *et al.* (1964). They underscore the seriousness of the difficulties arising from navigational disorientation, particularly when alternate routes and penetration corridors must be considered. We support their views and suggest that the terrain avoidance technique, which may involve frequent heading changes, requires that appropriate navigational and tactical information be readily available. However, we shall concentrate on the vertical situation aspects of terrain avoidance flight for two reasons. First, VSD problems are not so well documented as horizontal display problems and, hence, the need for discussion is greater. Second, depending upon the particular weapon system and data processors, it is possible to integrate some navigational and tactical information into the command steering logic of the VSD.

In our development of this section we depart somewhat from the method followed in the balance of the report. For one thing, we shall draw more heavily on our own experience and that of knowledgeable test pilots, and to a lesser degree on the literature. Also, we shall treat the topic as a whole rather than relegating questions of dynamics, scaling, display coverage, resolution, and the like to other chapters. Finally, most of our examples relate to experience with the terrain avoidance display of the A-6A aircraft. While general principles and information requirements derived here may be applied to terrain avoidance displays for other fixed wing aircraft, specific values cited for airspeed, g-factors, clearance altitude, and so forth are peculiar to the A-6A. Our intent is to illustrate the problem through a specific example and not to establish a definitive or universal solution. The reader is therefore cautioned about generalization from such specifics.

Display Requirements and Performance Criteria

An assumption implicit in our determination of display requirements for terrain avoidance is that, in addition to some degree of real world replication, a presentation of precision command data is required. The basis for this assumption is partly intuitive, partly empirical, and partly a carry-over from requirements established for all-weather instrument flight. It seems intuitively true that a display which has pictorial symbols corresponding to real world elements, such as terrain contour lines, will tend to build pilot confidence in the display. Empirical evidence from flight testing of the A-6A display and from flight and simulation studies of other displays (*e.g.*, Soliday and Milligan, 1967) tends to support the notion that display formats which combine pictorial status information and symbolic command information are effective in the low-altitude high-speed flight situation. Finally, we note that for some years the gyro horizon

and ILS cross pointers have been commonly, and successfully, used together during instrument landing. Although we are not able to assign comparative weights to each of the above factors, it does seem that realistic and easily interpreted status information about the vertical situation combined with superimposed command symbols will produce a display which is particularly suitable for terrain avoidance flying.

The effectiveness of performance in the vertical dimension for terrain avoidance (and terrain following) is usually judged in terms of how well the aircraft can parallel the terrain profile. In hugging the terrain the aircraft can degrade enemy radar detection and tracking capability by making maximum use of line-of-sight masking and ground clutter effects. Enemy capabilities are hard to assess because they change with the state of radar technology, with the success of electronic countermeasures and counter-countermeasures, and with the effectiveness and intensity of ground fire. For these reasons, it is difficult to obtain a solid and specific definition of what constitutes an acceptably low altitude at which to follow the terrain profile. In general, however, the objective is to match the terrain profile as closely as possible at some prescribed clearance altitude. An acceptable measure of the profile is *average clearance altitude*. It is also possible to express the profile match as the ratio of average clearance altitude to prescribed clearance altitude. In this case a value of 1 would indicate a perfect match, and values greater than 1 would indicate that the aircraft is overshooting the hilltops or not hugging the reverse slopes. Values less than 1 would suggest that the aircraft is coming undesirably close to the terrain.

To attain minimum average clearance altitude, experience with the A-6A display has shown that three principles should be observed:

1. a level-on-top trajectory should be programmed as part of the pitch command dynamics;

2. sufficient lead command should be provided so as to avoid command pull-up in excess of 1.5 g or push-over in excess of -1 g (both values incremental);

3. the total system mechanization should provide a defined but selectable hard minimum clearance altitude through which the aircraft never penetrates.

These are the special parameters which are useful in establishing terrain matching performance. As such, they help define terrain avoidance display information requirements.

One method of deriving a quantitative performance index for terrain avoidance or following systems is to describe the condition of the terrain *roughness* in terms of the percentage of altitude deviation from a mean value and then to correlate average clearance altitude, g envelope, and minimum clearance altitude with the terrain roughness. The effectiveness of a display/control mechanization can then be related directly to the ideal (computer solution) profile for a defined stretch of terrain.

Information Requirements for Terrain Avoidance

The following is a tabular summary of terrain avoidance data requirements as derived from our analysis. Supporting logic, explanations, and illustrations to justify these requirements are developed later in simplified form. The term *flight path* is used here to mean either the actual instantaneous velocity vector of the aircraft or a projection of it. Reference to a command flight path or an imaginary highway in the sky is not intended.

Table 16 TERRAIN AVOIDANCE INFORMATION REQUIREMENTS

PRIMARY

- o Terrain angle/altitude with respect to flight path
- o Terrain ranges
- o Vertical distance/clearance to terrain (radar altitude)
- o Azimuth or horizontal displacement of terrain with respect to flight path (turn data)
- o Flight path (heading and elevation)
- o Airspeed or throttle command
- o Climb (pitch) command
- o Attack and navigation steering commands

SECONDARY

- o Climb angle
- o Roll angle
- o Heading and turn rate
- o Altitude (sea level)

SUPPORT

- o Failure indication (including self test)
- o Calibration monitoring
- o Degradation (weather, water, or masking) fail safe logic

DATA INPUT (OPERATOR) REQUIREMENTS

- o Minimum altitude offset
- o Minimum en route altitude
- o Cruise airspeed

Terrain Elevation Angle and Altitude Control

The vertical dimension of a terrain display should indicate flight path and terrain elevation angle relationships. A strong case for this viewpoint can be made by considering the altitude management problem as it relates to the use of a longitudinal control system. Altitude control is normally attained by the combined use of thrust and longitudinal control. Theoretically, thrust variation provides the ability to change altitude at a constant airspeed, while longitudinal control enables the exchange of kinetic and potential energy. However, in practice, longitudinal control is used to provide short term altitude management, and thrust to provide long term altitude management. For example, potential-kinetic energy transfer at normal cruise speed for the A-6A provides an exchange of 25 feet per knot through a range of approximately 100 knots. Thus, fixed throttle at cruise speeds allows practical altitude variations up to ±2500 feet and permits exclusive use of the longitudinal control for altitude management in all but extremely rough terrain environments.

In order to use the longitudinal control system effectively for altitude management, the pilot's stick motion should relate to his view of altitude status as provided by the display. That is, the direction and amplitude of control movement should cause a status change which is proportional to the force of, and in line with, the control motion. In other words, the display of terrain elevation with respect to flight path should be vertically oriented in cockpit coordinates, and the rate at which the angle changes should be proportional to control force.

Because terrain avoidance control/display relationships are inherently complex, we will provide a simplified servo model to exemplify our approach to the problem before continuing with the analysis. Our intention is to be illustrative rather than comprehensive. We do not mean to imply that our simplified example, which makes use of only a single range to terrain, takes into account all the performance requirements of the A-6A, much less other low-altitude high-speed aircraft systems.

A Closed-Loop Servo Model for Deriving Information Requirements

A servo-oriented approach to cockpit display/control design treats the operator as a single-channel proportional element in a closed-loop system. The use of this concept can lead to a precise definition of pilot information requirements, symbol scaling, and display format. In addition, it can provide a convenient dynamic prediction model.

We have no wish to go deeply into the design philosophy which supports proportional displacement error and command rate for controlling that error. Instead, we will defend the validity of our servo model by comparing it with the ILS cockpit display as opposed to GCA. Pilots sometimes

express a lack of confidence in GCA even though performance statistics and failure and accident rates are comparable to ILS. There is, however, a considerable difference between the two systems. The GCA provides sampled, low speed, digital feedback through a voice link. It does not provide true proportional data. Consequently, the pilot is hard pressed to judge glideslope error rate in terms of precise changes of throttle or longitudinal control. On the other hand, the ILS cockpit display provides proportional error and error rate information which, by considerably less effort, is translated into thrust/pitch adjustments. The effect is to unload the pilot by using him as a simple servo follower. It is also possible to automate the system fully by closing the loop with an approach power compensator and ILS autopilot coupling. In this case, the pilot, by means of the display, becomes a system monitor. If the display presents proportional pitch/thrust data, he has a direct readout of automated system performance. More important, if the pilot should have to intervene, he has an immediate understanding of the situation and of the required control action. Note that the basic proportional error display is essential to the task regardless of the degree of automation and command computation.

Whatever approach or model one chooses, the main idea is to simplify a complex pilot task so that precise and repeatable performance results can be obtained. The servo model described below uses single channel proportional control as a means to this end.

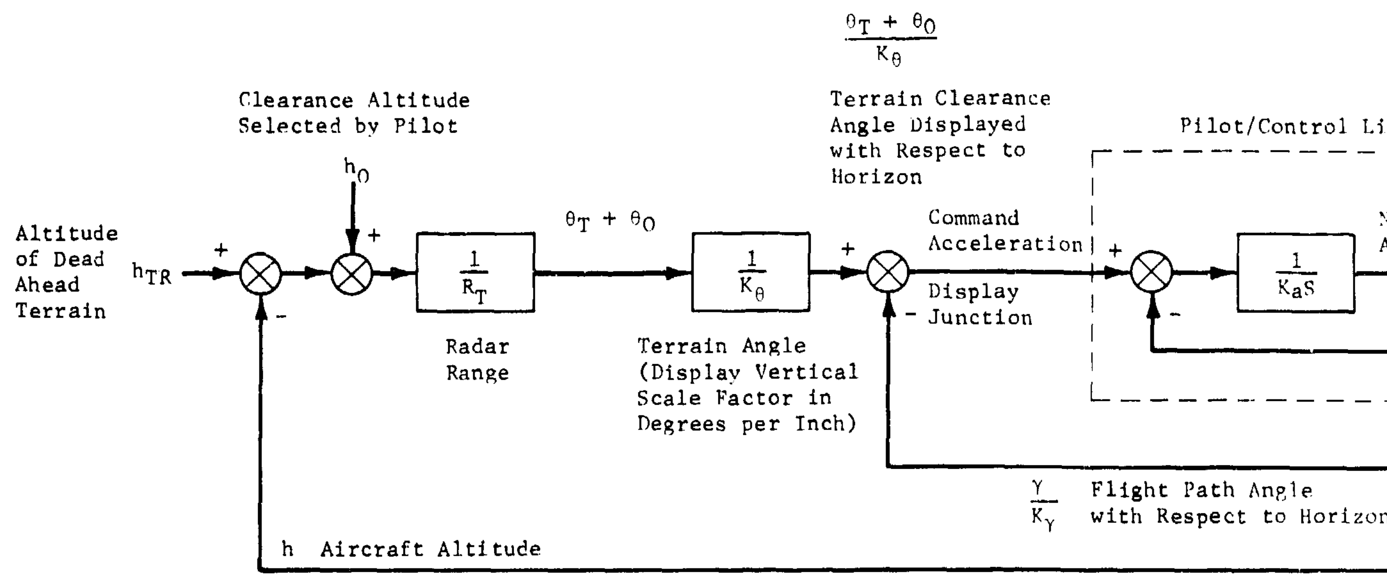


Figure 7a. BLOCK DIAGRAM FOR SINGLE RANGE TERRAIN FOLLOWING MODEL

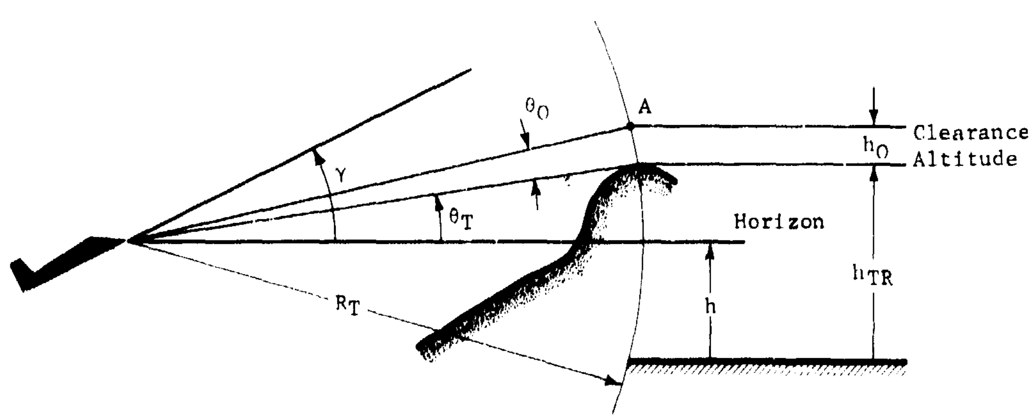


Figure 7b. PROFILE GEOMETRY FOR TERRAIN FOLLOWING

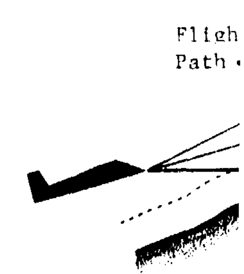
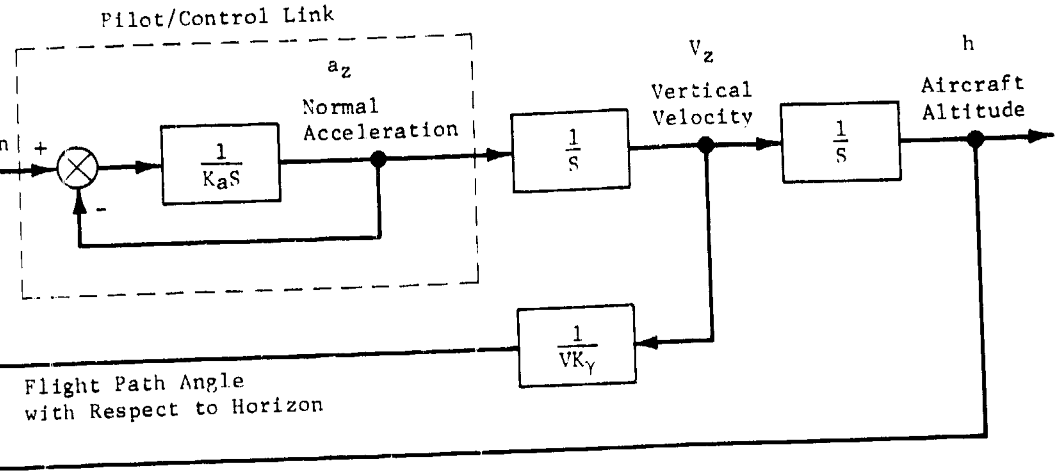


Figure 7c. FLIGI

Figure 7. TERRAIN FOLLOWING MODEL AND DISPLAY

A.



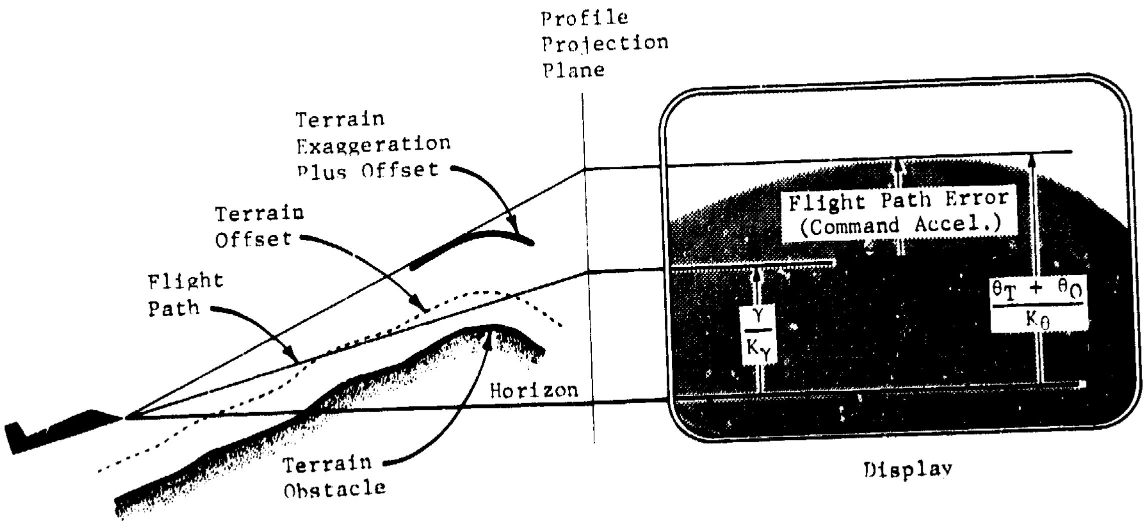


Figure 7c. FLIGHT PATH ORIENTED CONTACT ANALOG TERRAIN DISPLAY

B.

The servo model (Figure 7 a) indicates that the basic data requirements for manual terrain following are: 1) climb angle and 2) terrain plus offset clearance angle. The block diagram illustrates a simplified, single range schematic of a terrain following system. Altitude (h_{TR}), with respect to sea level, of the terrain dead ahead at an arbitrary range (R_T) is used to describe a time-varying terrain condition. The addition of offset altitude (h_O) and the subtraction of aircraft altitude (h) from h_{TR} yields the altitude error between the instantaneous aircraft position and the desired clearance altitude (Point A of Figure 7 b). This quantity divided by both R_T and K_Θ (display scale factor) provides the terrain dimension above the display horizon. Display input is then completed at the *display junction* by use of climb angle (γ) divided by the horizon scaling factor (K_γ). The pilot controls the climb angle through the longitudinal control system, which allows him to match the terrain offset angle. In practice he manipulates the longitudinal control system so as to create a normal acceleration (a_z) which he maintains proportionally to the matching error. The first integral of a_z is vertical velocity (V_z), and the second integral is altitude (h). Vertical velocity is used to derive climb angle by use of aircraft velocity (V), whereas h is used to close the servo model loop.

In summary, the servo model illustrates that the essential information for a pure terrain following (*i.e.*, altitude management) display is terrain clearance angle referenced to flight path.

Continuing with the servo model example, it can be shown that properly scaled climb angle and clearance point information will provide a compatible display both for pilot manual control and for monitoring of an automatic system. Referring to Figure 7 c, the climb angle scaled with respect to the horizon is γ/K_γ inches, where γ is in degrees and K_γ is in degrees per inch. The clearance point angle with respect to the horizon is $(\Theta_T + \Theta_O)/K_\Theta$ inches, where Θ_T and Θ_O are in degrees and K_Θ is in degrees per inch. The pilot matches the two symbols through use of the longitudinal control system causing γ/K_γ to equal $(\Theta_T + \Theta_O)/K_\Theta$. Climb angle is therefore controlled as a direct function of terrain angle such that $\gamma = K_\gamma(\Theta_T + \Theta_O)/K_\Theta$. Note that the value of K_γ is changed from K_Θ for nose down to approximately $2K_\Theta$ for nose up so as to achieve proper trajectory (level on top).

The servo model provides a terrain following climb command which is displayed in terms of proportional longitudinal control displacement. The climb command input to the pilot generates a control response which is proportional to an available cockpit control, in this case the longitudinal stick position. The simplified first order approximation of pilot response is represented by the *pilot/control link* in Figure 7 a. The command input to this link is a time-varying error function which requires control of flight path angle in order to achieve proper altitude control. Pilot stick displacement at constant speed is designed to provide proportional normal acceleration or rate of change of flight path angle. Thus, the displayed difference between terrain and flight path angle is a direct stick force or normal acceleration command. The controlled variable is

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directly related to an available cockpit control. This provides the desired linear-proportional relationship between display and control and makes use of the pilot as a first order linear control element. These control methods should promote a degree of confidence in the display by correlating the normal pilot control response with command and status display cues.

The reason for developing the above model in some detail is to familiarize the reader with terrain following problems in precise terms. However, before continuing with the technical aspects of the discussion, a point of a more general nature should be made.

Pilot Confidence in Low Altitude Systems

Pilot confidence in the display is of overriding importance in low altitude flying. Any low altitude display or navigation system must provide consistent and accurate performance to gain acceptance by the pilot. The potential danger of collision with the ground creates a strong psychological block which must be dealt with in display/control system design. Neither a pure command display nor a pure status display is wholly adequate for low altitude operation. For the pilot to recognize and accept the validity of a pure command display requires extensive experience with it. Even so, basic pilot confidence never reaches 100 per cent. On the other hand, the validity of a pure status display is much more easily recognized, but precision performance is hard to attain because of the training and long experience necessary to interpret the display with the required accuracy and speed. The proficiency required to obtain consistent and repeatable flight results is not only hard to attain, it also requires constant practice to keep it up. Thus, a pure status display might be acceptable in a situation where there is a wide margin for error, but it is of limited utility in a close approach to the terrain which calls for great precision.

A serious fault of many automatic terrain following systems is the lack of effective monitoring capability for the pilot. As we have said, confidence is the key to a successful display for low altitude flight, and one of the prime factors in building confidence is the ability to show correlation between the normal pilot control response and a command or autopilot response. Without this correlation, the pilot is forced to accept the autopilot response on the basis of his interpretation of a status display which, itself, may bear little direct relation to his own flying techniques. A display/control system such as this is as awkward to fly as it is to explain.

Three questions emerge as general guides for evaluating the confidence factor of status and command displays for low altitude flight. First, is the status information easily associated with the real world? Second, is command information related to status information in a simple, meaningful way which is compatible with normal pilot control responses? Third, does

the display promote consistent and accurate performance? A display system satisfying these criteria will be one which pilots will come to accept as flyable and trustworthy.

Display Field of View, Scaling, and Dynamics

Space does not permit us to give a full development of each of the topics listed below. Therefore, we shall confine the discussion to essential points and hope that it will adequately highlight the main problem areas. Here again, all reference values and system parameters are drawn from flight test experience with the A-6A terrain avoidance display.

1. Vertical Field of View

The down-look angle limit and the maximum range of a terrain avoidance display system should provide coverage which is sufficient to avoid loss of contact with the terrain during pitch up maneuvers. Thus, the vertical field of view required on the display is partially defined by the maximum command climb angle and by the terrain upslope angle. Experience has shown that the instantaneous command climb angle and sustained terrain upslope seldom exceed +25°. Therefore, a maximum down-look angle of -25° is required to maintain line of sight contact with the terrain during pull-up.

The maximum range of the sensor system must also be considered in deriving the field of view requirement because push over should not be initiated without a display of the terrain, Generally, the greater the range capability of the system, the more probable the detection of low angle terrain.

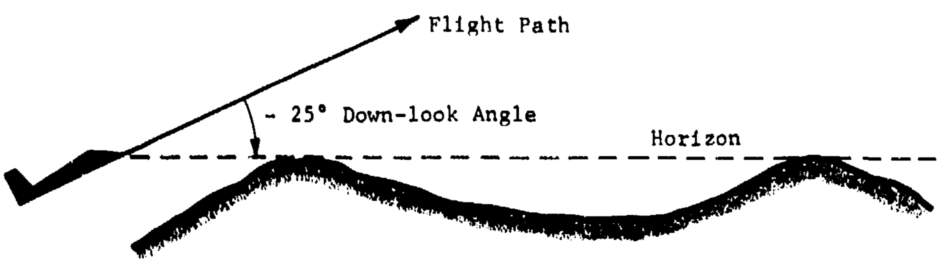

Figure 8 DOWN-LOOK ANGLE AND LINE OF SIGHT TO LONG RANGE TERRAIN

The up-look angle of a terrain following or avoidance system should provide coverage which identifies dangerous obstacles in relation to aircraft climb performance and g-envelope. For the A-6A this angle is estimated to be approximately +10°.

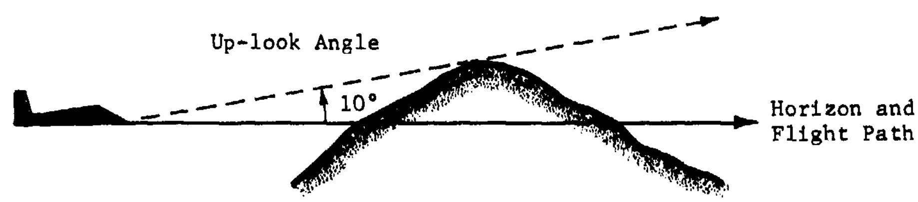

Figure 9 REQUIRED UP-LOOK ANGLE (ESTIMATED) FOR TERRAIN DISPLAY

Note that a scale factor of 10° per inch on a display whose vertical dimension is 6 inches provides a coverage of ±30° vertically about the aircraft flight path and amply satisfies the +10° to -25° field of view requirement derived above.

2. Range

Maximum range (R_{max}) sensing or display range limit must take into account aircraft climb performance and maximum altitude cruise conditions. The determination of maximum range in relation to climb performance is a matter of selecting a worst case terrain obstacle height and using it as shown in Figure 10.

$$R_{max} = \frac{h_{max}}{\tan \theta_s} \qquad \text{Where } \theta_s \text{ is maximum sustainable climb angle}$$

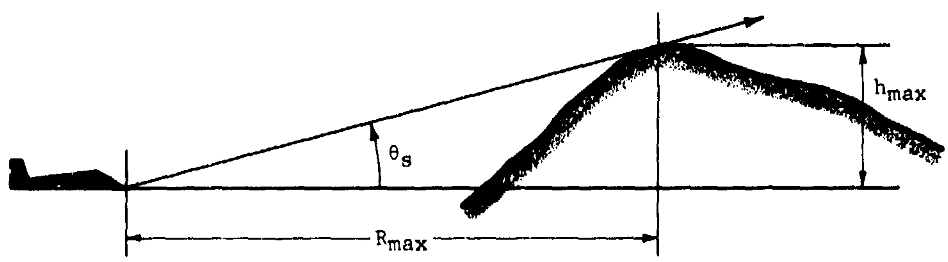

Figure 10 MAXIMUM SUSTAINABLE CLIMB ANGLE RELATED TO RANGE SENSING AND DISPLAY

Extreme terrain roughness might call for a sustained climb to clear an obstacle 10,000 feet above the flight path. Applying the formula in Figure 10, we see that the system must have a 10 nautical mile detection range, assuming a climb angle limit of 10°.

A bomber and a fighter will usually differ in the θ_s values and will therefore require a display of different maximum range for terrain following or avoidance. For example, a 5° climb angle is a conservative estimate for a jet bomber; and if h_{max} is set at 10,000 feet, a value of 20 nautical miles is appropriate for R_{max}.

A second consideration in establishing R_{max} relates to display test and check-out at high cruising altitudes. If display adjustments are to be

made prior to descent and if the system is to be tested in flight before its actual use, terrain return video should be available from a range which is proportional to the maximum downward viewing angle at cruise altitude. For example, if cruise at 30,000 feet above the terrain is combined with a downward view limit of -15°, the R_{max} should be at least 20, and preferably 25 to 30, nautical miles.

Minimum range for a terrain avoidance or following display is determined by the required minimum clearance altitude, minimum ground speed, and the zero g trajectory to impact. See Figure 11. For example, at a

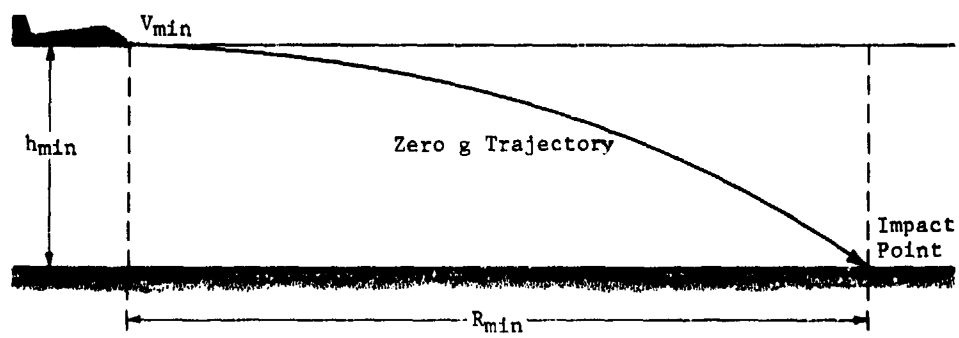

Figure 11 PARAMETERS OF MINIMUM DISPLAY RANGE FOR TERRAIN AVOIDANCE

velocity (V_{min}) of 200 knots and at an altitude (h_{min}) of 200 feet, the minimum range capability (R_{min}) of the display system works out to be approximately 1200 feet.

3. Close-in Range Resolution and Obstacle Avoidance

Normal pull-up commands to avoid an obstacle at close range should be such that the vertical g-factor does not exceed 2 g (*i.e.*, 1 g over normal). Since it was postulated earlier that sufficient lead command should be provided to avoid pull-ups in excess of 1.5 incremental g, limiting the normal command to 1 g will provide a margin of safety for the emergency pull-up situation. The pull-up command limit, coupled with the minimum terrain clearance altitude selected for the system, will serve to determine

an altitude control point which must be accurately measured for any given ground speed. For example, if we assume a minimum clearance altitude of 200 feet and a ground speed of 500 knots, the control point is approximately 2100 feet ahead of the aircraft and about 5.5° below the horizon. At 200 feet clearance altitude in level flight over a flat terrain, the sensor/display system should provide altitude control about this point to within ±20 feet (*i.e.*, a tolerance of ±10%).

4. Climb Angle Scaling and Kinetic Energy Management

The critical problem in low altitude flight is to climb out over sharply rising terrain. Long range terrain sensing is a partial solution to the problem in that the system will provide early warning of steep gradients and allow the pilot time for anticipatory action. There remains, however, the problem of encountering a high terrain rise at close range, such as might happen if the aircraft turned into a blind valley or a box canyon. The problem is especially severe for heavily loaded or low performance aircraft, and particular attention must be given to creating a display whose pull-up commands do not force the aircraft into an impossible climb-out situation. This entails scaling of climb angle and emergency pull-up commands in terms of the climb performance limits of the aircraft.

The essential element of the climb-out problem is kinetic energy management, which is to say that the pilot must maintain sufficient airspeed for maximum angle climb if needed. Terrain avoidance or terrain following is usually carried out at a speed which will provide maximum cruising range. Fortunately, maximum angle climb for an aircraft is obtained at an airspeed somewhat below that appropriate for maximum range cruise. Thus, the normally available excess of airspeed will work in the pilot's favor so long as pull-up commands are based upon the climb angle performance attainable at maximum range cruise speed and military power setting. In this way a practical safety factor is achieved in that maximum angle climb can be held in reserve for an emergency. An additional safety factor can be created through an automatic throttle control which provides a programmed application of more power if airspeed falls below a safe level. If this is not available or feasible for the particular aircraft, the display system should at least provide a warning to the pilot to add power manually. This requirement can be satisfied by the display of either airspeed or throttle command information.

In the event an emergency pull-up becomes necessary, the display system should generate commands which will result in:

a) transition to the attitude required for maximum angle climb or for attaining the selected minimum en route altitude in the shortest time;

b) automatic or manual application of military power.

The same commands should be provided in case of system failure, which should be treated as a situation requiring emergency pull-up to the preselected minimum en route altitude.

5. Level-on-top Trajectory Built into Elevation Scaling

One of the ground rules needed to obtain the desired performance characteristics in a low altitude display is that the aircraft flight path should be horizontal at the top of an obstacle. One means of attaining this level-on-top performance is to exaggerate on the display the elevation angle of terrain above the aircraft flight path. From experience it appears that a factor of about 2 will yield the desired results. The pilot is thus directed by the display to adjust his flight path to a climb angle double that which he would use in proceeding directly to the obstacle. As he climbs to follow the exaggerated terrain, he will eventually arrive at the altitude of the obstacle (plus the clearance altitude) before he passes over it. Since the obstacle will then lie on or below the flight path, its elevation will be presented on the display without exaggeration, *i.e.*, at display center or slightly below it in true proportion to the line of sight to the obstacle. As the obstacle moves progressively down the display and the pilot tracks it, he will decrease the climb angle and eventually reach level flight as he clears the obstacle. Figure 12 illustrates the trajectory achieved by causing an obstacle (A) to appear on the display at an exaggerated height (A'). The other notation is the same as that given earlier in the servo model (Figure 7).

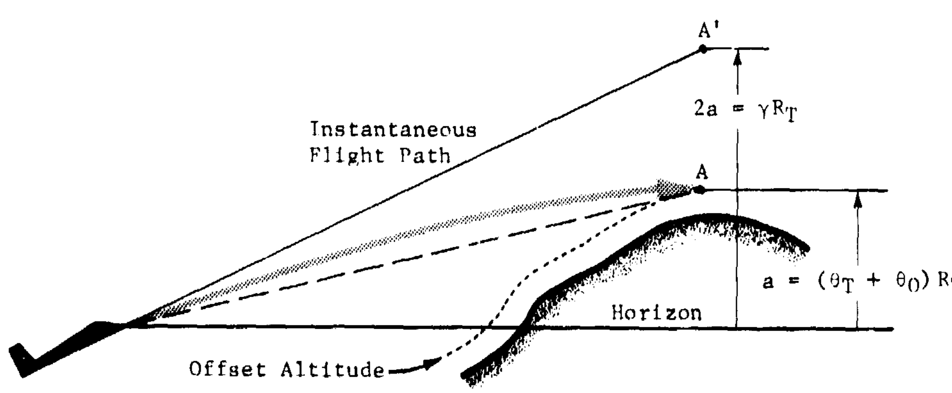

Figure 12 LEVEL-ON-TOP TRAJECTORY ACHIEVED BY TERRAIN EXAGGERATION

6. Hard Minimum Radar Altitude

An important part of the performance desired of a terrain avoidance or terrain following system is that a selectable but *hard* minimum clearance altitude is achieved. The selection of this minimum altitude will depend upon the mission, the enemy radar defenses, and the type of terrain over which the aircraft must fly; but whatever it might be, the system should prevent penetration below this altitude. One way of achieving this is to use radar (absolute) altitude as an integral part of the display. This should be done in such a manner that:

a) effective minimum altitude protection is achieved;

b) the descent trajectory over water is safely and accurately controlled;

c) positive indication of crest clearance is provided;

d) impossible altitude and dive angle combinations are avoided.

This means that the display should be mechanized so as to provide a command dive angle which is proportional to radar altitude plus a selected clearance offset. See Figure 13.

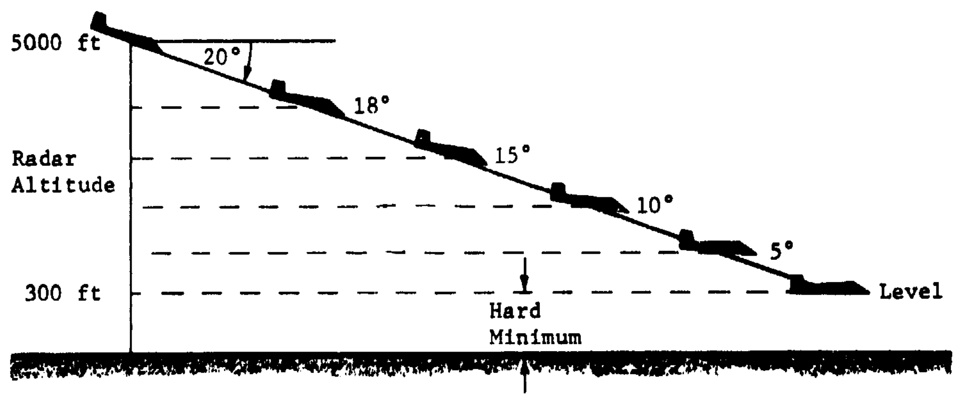

Figure 13 DESCENT TRAJECTORY ACHIEVED BY USE OF RADAR ALTITUDE FLIGHT PATH DATA

In no case should the radar altimeter by itself be used to supplement a terrain display. Radar altitude information must be integrated into the display, not just to achieve the command dynamic described above, but also to avoid the degradation in performance and survival factors which result from making the pilot cross scan to obtain basic information about the low level flight situation.

7. Terrain Azimuth Reference and Horizontal Field of View

There is considerable controversy about the best method for presenting information about the terrain which lies to the right and left of the aircraft flight path. While this information is not critical for terrain following, it is absolutely essential for terrain avoidance, where the pilot must have a display which permits him to maneuver laterally around obstacles and to follow valleys. The E-scan format does not seem to be a satisfactory way to present terrain azimuth information, which rules out this type of display for terrain avoidance. The use of E-scan time-shared with a PPI display does not seem to be a suitable compromise since it requires the pilot to divide his attention between two displays and places upon him the burden of integrating the two views of the situation into a three-dimensional picture. The C-scan display, which we have described here, offers the most promise as a presentation of status and command information for terrain avoidance.

There are, however, unresolved questions in connection with the C-scan (azimuth-elevation) format. One of the most vexing is that of the proper reference for the azimuth scan. One choice is to center the display, laterally, about the <u>instantaneous</u> flight path of the aircraft. If, as we have suggested earlier, the display is also centered vertically about the flight path, this method has the advantage of giving the pilot a single point of reference for pitch and bank maneuvers. However, such a display makes flying parallel to a steep wall perilous. Drift or turn into steeply rising terrain can quickly overtax the capability for effective pull-up and can result in impact. As an alternative, the display can be referenced in azimuth to the <u>predicted</u> trajectory or flight path. While this lessens the danger of paralleling a wall, it creates the equally grave danger of a blind spot along the instantaneous trajectory during turns. A possible solution may be found in a display which makes use of an azimuth offset angle, analogous to the vertical offset or hard minimum clearance altitude discussed earlier. The question is far from settled, however, and more research on this topic is badly needed.

A related topic is that of horizontal field of view. It seems obvious that for maneuvering around obstacles the pilot needs as wide a horizontal field of view as possible. But just how wide is this? If we consider just the display itself, we find conflicting requirements. A veridical or contact analog display such as suggested by the discussion up to this point entails, according to some, a one-to-one correspondence between the

angular dimensions of the display and the real world scene represented. A display 8 inches wide viewed from a distance of 15 inches subtends a visual angle of about 30°. A horizontal field of view of ±15° seems a bit restricted for terrain avoidance purposes considering the agility and speed of attack aircraft. Thus, it would appear that the terrain avoidance contact analog display calls for a tube considerably wider than the 8-inch CRT now in common use, which in turn will create problems in fitting the display into limited instrument panel space. We have suggested earlier that a scale factor of 10° per inch is appropriate for the vertical dimension of the display. Assuming again an 8-inch display, this would yield a ±40° field of view if the same scale factor were to be applied horizontally. While this accords much better with aircraft maneuver capability, it poses a formidable problem for the terrain sensing portion of the system. To scan an area 60° x 80° at the speed necessary to maintain a frequently up-dated terrain picture requires a broad beam sensor, a box scan, or both. To attain this large scan volume may also entail an unacceptable sacrifice in range resolution and accuracy. It would seem that display requirements outstrip the state of development of sensor systems.

The situation becomes even more difficult if aircraft maneuver requirements are considered. One of the most extreme maneuvers called for is SAM avoidance. This may require simultaneous acceleration in three axes coupled with a rapid descent. In visual contact flight this can be accomplished by a sharp roll with a high-g pull-through, *i.e.*, a modified split-S maneuver. In order to accomplish this same maneuver on instruments over unknown terrain, the vertical scan of the display/sensor system must be unrestricted by roll angle and extend to an extreme dive angle (*e.g.*, 70°). Further, azimuth coverage must be sufficient to allow rapid turning. To obtain a display which is not maneuver restricted requires that, together with unlimited roll, a scan of ±60° in azimuth be provided.

It seems clear that additional research and testing are needed before recommendations can be made in this area. Trade-offs are most certainly called for, but this will require a more solid basis than now exists for assigning weights to the various display, aircraft, and equipment factors. In all probability no one general solution will be found, but rather particular compromises suited to a given aircraft with certain mission requirements, performance characteristics, and sensor/display capabilities.

Summary

A number of basic design questions in regard to terrain avoidance have been raised in this section, and some practical solutions have been offered, but we have only peeled back the first layer or two of the problem. The information requirements list given at the beginning stems largely from our own analysis of the problem. Our comments relating to display

dynamics, scaling, and field of view are based on design concepts which we believe to be workable but which have not been fully tested. We neither expect nor desire that the reader accept our views on face value as definitive or conclusive.

It may seem presumptuous to offer our personal views on the subject of terrain avoidance without citing experimental evidence to support them and without an exposition of other points of view. In defense we point out that there is relatively little research information available. The evaluative study by Soliday and Milligan (1967) is a careful and comprehensive work, but there are too few like it. Many reports that we have seen on the subject of low altitude flight displays and terrain avoidance or following systems are flawed by prejudice for a particular format or mechanization or by lack of depth and balance in the analysis of system requirements. While this is regrettable, it should not be taken as a reflection on the ability or integrity of those involved. Rather, it is an indication of the complexity and difficulty of the low altitude flight problem and of the insufficiency of accumulated research evidence and flight test experience from which to work.

It seems clear that standardization in this area is not yet attainable and that extensive research is required before it will be. Our goal here has been simply to introduce the significant problems and to present enough of the terminology and analytic approach to provide preliminary orientation. However, one conclusion is inescapable. The low altitude flight problem highlights the need for a systems approach in seeking solutions. It is not a question of the display alone, nor even of the display in conjunction with the sensors and data processors. A successful design must take into account the system as a whole and achieve its results by harmonizing the capabilities of the display and its associated sensing and processing equipment with the performance of the aircraft, the demands of its mission, and the needs of the human operator.

WEAPON DELIVERY

Information requirements for weapon delivery may be divided into two broad classes: information necessary for control or aiming of the aircraft and information relating to the specific parameters of the weapon and its tactical employment. With respect to the first, weapon delivery is much like any other mission phase. Generally speaking, the pilot needs to know his attitude, speed, and altitude; and he must have some indication of the proper flight path or aiming point. To some extent, control of the aircraft for weapon delivery may differ from other mission phases in that higher performance and more extreme maneuvers are usually demanded. Larger and more unusual pitch and roll angles may be called for, and they may vary across a wider range and more rapidly than in other mission phases. Velocities and accelerations are also usually higher. In addition, weapon delivery is a more demanding exercise because accuracies are much higher and tolerances much closer. In terms of precise flight control, weapon delivery is like landing except that the speed and range of performance are much greater. All these, however, are differences of degree not kind; and weapon delivery imposes no new information requirements insofar as flight control is concerned.

In terms of weapon parameters and methods of delivery, E/O display content is highly specialized. The information requirements of the display will be determined by combinations of several variables, each more or less peculiar to the individual weapon and aircraft system. Some of these variables are:

- Weapon class - Air-to-air, air-to-ground, air-to-subsurface
- Weapon type - Missile, gravity bomb, glide bomb, rocket, cannon, machine gun, depth charges, etc.
- Warhead type - Nuclear or conventional
- Weapon performance and peculiarities - Range, self-guidance, remote guidance, maneuver capability, arming and fuzing, delivery accuracy, burst radius, etc.
- Sensor system - Visual, radar, IR, video, laser, anti-radiation, etc.
- Fire control system - Degree of automation, type of steering or aiming, multiple or single target capability, alternate solution, etc.
- Delivery maneuver - Dive, toss, loft, lay down, over the shoulder, standoff, etc.
- Type of display - Direct view VSD, HUD, HSD, MSD

- o Crew member - Pilot, bombardier, ECM operator, etc.
- o Aircraft type - Mission, performance characteristics, fixed or rotary wing

Because of the number of variables and the possible number of interactions, it is hard to arrive at any meaningful generalizations about the information content of weapon delivery displays. Each weapon system is virtually unique, and the variety is bewildering. Our review of the literature and survey of current display designs have turned up very little information which is not peculiar either to a given weapon or to a given aircraft and its weapon inventory. In the latter case, the displays tend to have several modes, one for each weapon or tactical use, and so they are not truly general purpose displays. An additional complication has been introduced by the security classification of many weapons and weapon systems. This has prevented us from having full access to research documents and equipment specifications, and it precludes us from presenting illustrations and weapon system details in an unclassified report such as this. For these reasons, our coverage of information requirements for weapon delivery will be only summary.

In the broadest terms, weapon delivery displays should contain at least these kinds of information:

1. Target location and identification
2. Range or time until release
3. Aiming point and error tolerance
4. Delivery guidance (maneuver, release command, and in-flight guidance of the weapon, if appropriate)
5. Weapon state or readiness

To these, of course, must be added information necessary to maintain control of the aircraft and whatever other special items that may be imposed by the fire control system, nuclear weapon requirements, weapon peculiarities, and aircraft performance and safety considerations. We wish to emphasize that the foregoing is entirely our own view; and while it is consistent with the scant findings of our literature search and display survey, we do not purport that it is generally held.

We do not believe that weapon delivery displays can be standardized at this time, except in the very broad terms outlined above. For the time being, designers should be allowed freedom to create weapon delivery displays tailored to each weapon or aircraft system so long as the content of these displays remains generally consistent with the needs of flight control and

crew safety. In the long run, however, some general standard or set of guides will be needed. Initially, effort should be directed to developing uniform information requirements lists for each class or family of weapons. To do this it will probably also be necessary to make certain assumptions about the aircraft type and mission and about the sensors and fire control system. Almost certainly, such requirements lists will not be comprehensive. They will indicate only the minimum of information required, and it will still be necessary, and desirable, to allow designers the option of adding information items peculiar to the weapon and its tactical use.

To the above end, feedback from combat pilots and maintenance personnel should be systematically collected and evaluated. Often the information believed appropriate by engineers and display designers does not prove to be the most meaningful or useful in an operational environment. This results from a number of factors including a lack of early development phase planning and analysis. The complexities of target location, weapon selection, firing logic, terrain avoidance, task loading, and safe exit either cannot be or are not efficiently resolved after prototype hardware configurations have been frozen. Although combat zone feedback is important, it is supplemental to the main task of a thorough, early system design.

Similarly, controlled simulation studies are a valuable source of information. Efforts such as those under way at NADC/Johnsville and USNMC/Point Mugu for the Phoenix Missile System yield useful data on weapon delivery display requirements. Such studies are especially helpful in resolving the problems of display scaling, symbol dynamics, and operational task sequencing which have been noted in the early design stage.

INTRODUCTION

If there is any one distinguishing feature of E/O displays, it is the degree of freedom they offer the display designer in the selection of symbols, formats, and modes of presentation. The E/O display permits the designer not only to put the information in its best form but also, through mode switching, to achieve optimum combinations of symbols (and hence information) for any given purpose. This flexibility and versatility stands out clearly in the survey of E/O displays in the preceeding chapter. Yet, it is also evident from the survey that freedom of choice is not an unqualified boon. One's first impression is that there are almost as many sets of symbols as there are displays and designers and that there is a divergence of opinion on almost every aspect of symbology.

Honigfeld (1964), discussing the need for a standard radar symbology, summarizes the problem in the following way.

> *"The need for a standard symbology is highlighted by the fact that each contractor who develops a radar system has, in the past, been allowed to arbitrarily select a symbol code and its meaning for display use. Since symbols have not been specified formally, the result is a unique code for each system. Symbol meanings differ from system to system; identical meanings might be represented on one display by numbers, on another by letters, and on a third by geometric forms.*
>
> *"As the variety of systems increases and obsolete systems are phased out, personnel are taken from one system, retrained, and reassigned to new systems. The vast literature on human learning shows the interference and inefficiency which results from conflicting habits. Habit interference is particularly disrupting when familiar stimuli require a new set of responses in a new task. This inefficiency is enhanced under stress conditions, where people revert to earlier experience and respond as they did in previous situations. In the often stressful atmosphere of radar operation, an operator may revert to his old mode of response and designate an enemy as a friend or vice versa. This possibility necessitates the standardization of radar-display codes."*

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Though directed specifically to the problem of radar displays, Honigfeld's observations are equally valid for the whole field of E/O displays.

More recently, Walchli (1967) recognizes the same problem in an area a little closer to home. In his Head-Up Display Review he poses the question, *"What symbols should be used to encode the information?"* From his survey of the literature relating to the design of current head-up displays he concludes that:

> *"No reliable indication of the criteria used to select these symbols is apparent from the referenced reports. The symbols used to code the physical features (of the real world) probably were selected to retain the dominant physical characteristics of the item represented. The symbols chosen to code the various flight parameters, however, seem to be the product of tradeoffs between a "best-guess" choice and the image generation capabilities of the various display systems."*

Thus, it appears that at the present time we are confronted with a situation where we have a medium offering exceptional possibilities for displaying information but which we are not making best use of because of disagreement and uncertainty about the principles for encoding the information. The penalties for this indecision are significant in terms of cost, system efficiency, training and retraining requirements, and - ultimately - crew safety and mission success.

That the armed services recognize the need for a solution to this problem is evidenced by the existence of the Aircrew Station Standardization Panel and by the work of the JANAIR program. Those who design and experiment with E/O displays also recognize that their tasks could be simplified by a standard symbology or display language. Yet, user and designer alike are reluctant to give up any of their latitude of choice in matters of symbology except in the face of the most conclusive evidence. Some are opposed to standardization, in any restrictive sense, since they fear it would limit unnecessarily the range of possible design solutions or would hinder the eventual development of an optimum display language. Others see great value in standardization but caution against the premature setting of standards. Still others doubt that standardization is possible at all since the selection of a display language, a symbology, depends upon the nature of the pilot's several tasks, his information needs, mission requirements, aircraft type, and related system factors - all of which are so highly variable in themselves that generalizations, of the sort necessary to support a common display language, are not possible. It is in the area of symbology, then, that the need for standardization is the greatest and, paradoxically, that standardization will be the most difficult to achieve.

The point of departure for this chapter is the same as that of Honigfeld and Walchli in their previously cited studies, except that the scope of the present inquiry includes a greater variety of E/O displays. The central questions of this chapter are:

What bases exist for a standard symbology?

What particular form should it take?

The broader question of the wisdom of standardization, though germane to this examination, is largely philosophical and beyond the scope of the inquiry and our power to resolve.

At the outset it is necessary to clarify the meaning of the term, symbology, as it is used in this study. First, symbology is concerned with the formal properties of symbols. This includes not only absolute properties such as shape, size, color, and brightness, but also the relationships between form and meaning, the correspondences between the symbol and the thing symbolized. Second, symbology is concerned with the grouping of symbols within a display. This involves consideration of the overall framework or pattern of presentation - what Roscoe (1967) calls the *"common reference system which allows relationships among the items to be perceived directly"*. However, grouping also entails attaining an orderly arrangement of symbols to prevent interference between symbols, to avoid overlap and obscuration, and to conform with certain conventions, habits of use, and operator expectations. Finally, symbology deals with the dynamic properties of symbols. This means not only the degrees of freedom of individual display elements but also the movement patterns of groups of symbols and the relationship of this movement to system dynamics and the perceived movement of the real world.

In theory, the principles of symbology might be expected to hold true irrespective of the particular display application, but in practice certain other factors come into play. In formulating rules for symbology, consideration must be given to other characteristics of the display and to the system in which the display is employed. For example, the type of display - VSD or HSD - must be considered. The same symbol which represents heading on a map display may prove inappropriate or inadequate for representing heading on a vertical situation flight director display. Likewise, symbology may differ depending upon whether the particular display is of the direct view or projected type. The line width appropriate for symbols on a direct view display, where background and contrast can be controlled, may not be suitable for a head-up display, where background brightness and terrain texture are not under the designer's control. In a similar fashion, symbology will be influenced by such factors as the technique of generation (line written vs. raster displays), the size of the display, the viewing distance, and the location of the display within the operator's field of view. As a final example, it is evident that the aircraft and its mission have an influence on symbology. An armed helicopter, a fixed wing light reconnaissance aircraft, and a supersonic interceptor each pose

special problems in the area of symbology for which aircraft- and mission-peculiar solutions must be found. No general set of rules can be expected to govern fully all such cases.

This chapter on symbology begins with a review of the available research literature to identify the significant findings of other investigators and to isolate the important human variables relating to symbology. These will be generalized, insofar as possible, to form a set of principles which will then be applied to the design of specific symbols for representing the information identified in Chapter III as requirements.

CODING THEORY AND PRINCIPLES

The basic purpose of a display is to provide the user with the information he needs for assessment of the situation, decision making, and control action. However, most displays are two-dimensional while the real world with which the man must interact usually varies along three, four, or even more dimensions. Hence, the display designer must find methods of presenting (encoding) these additional dimensions within the display framework. The usefulness of any coding method lies in the extent to which it enables one to facilitate the user's information processing tasks. The coding of information entails consideration of the different visual tasks required of the operator. It also requires that human perceptual and discriminative capacities and limitations be taken into account.

Gebhard (1949) analyzed the psychological problems related to interpretability of visual coding in displays and summarized his findings as follows:

> "1. *The conventional two-dimensional display is only satisfactory for presenting two-variable information.*
>
> 2. *It is desirable to get more variables into the display.*
>
> 3. *Coding provides a way of doing this.*
>
> 4. *Coding may be done by varying the display elements in color, brightness, size, intermittence, and shape. These may be used in combination.*
>
> 5. *To assess the utility of these codes will require much fundamental research in discriminability, scaling, and learning.*
>
> 6. *A display of many elements, each complexly coded, may make a simple display completely incomprehensible.*
>
> 7. *Therefore, the problem of interpretability must be studied in the final phase of the work on coding."*

In the succeeding twenty years considerable thought and research have been directed to these ends. Generally, investigation has proceeded along two lines - efforts to establish a theory of coding and attempts to arrive at practical rules or guides for the selection of codes. That these two lines of activity have not always been coordinated is noted by Sampson and Wade (1961) who remark that progress in developing display principles and techniques has proceeded largely on an empirical basis. The explanations of why various techniques work are usually *ad hoc* and, for the most part, unrelated to basic theory of human behavior. They observe that, in other applied areas, attempts to relate to basic psychological theory have resulted in the discovery of new principles in the applied area. They conclude that the possibility of discovering new principles and the fruits of past developments of integrated displays would seem to justify continued research in this direction.

There seems to be little doubt that a general theory of coding is desirable, and perhaps eventually achievable. There is considerably less unanimity about how to arrive at such a theory. Honigfeld (1964) suggests that a basis for coding theory might be found in Gestalt psychology, specifically in the *Law of Praegnanz*. This law, Hongifeld explains, refers to the way an entire visual field is differentiated and organized perceptually into *figure* and *ground*. It gives *figural goodness* as the goal of perception. *Good* shapes and patterns are generally described as having few parts and being homogeneous, regular, symmetrical or, in short simple. What the object's shape lacks in *goodness* may be added by the observer in perceiving its form. Honigfeld offers a list of the Gestalt theories relating to the perception of characteristic patterns, among which are Predominance of Figure over Ground, Significance of Contours, Simplicity, Symmetry, and Similarity of Behavior (*Common Fate*). After examining the findings of a number of investigators in this area, Honigfeld concludes:

> *"Gestalt principles of perception would appear to have limited usefulness in developing radar symbology. Such concepts as simplicity of form and symmetry have received only mixed support in symbology research. While there are a number of parameters for constructing distinctive shapes, there are no general rules, since a shape's recognition value is only partly dependent on its geometric construction. The recognition value of a form is also dependent on its similarity to other forms being used, the number of other forms, and the observer's familiarity with it."*

An alternative is to be found in *Information Theory*, which is not so much a theory as a relatively new interdisciplinary field of study concerned with developing mathematical concepts about the communication of information. It is akin to, but broader in scope than, the communication theory from which it developed. Information theory seeks to quantify the transmission

of information in terms of the *efficiency* and *channel capacity* of a communication system, which in the present context may be taken to mean the observer-display loop. Information gotten out without being put in, *i.e.,* added in transmission, is called *noise*. The freedom from *equivocation* and *noise* is the measure of the efficiency of the system. The asymptotic point beyond which increased input fails to result in an increase of transmitted information marks the *channel capacity* of the observer. This is the upper limit of the observer's ability to match responses to stimuli.

Advocates maintain that the theory permits coding techniques to be compared quantitatively as to capacity and efficiency and that the effects of noise can be systematically controlled. Thus far, the emphasis in information theory has been more on the side of communication engineering than on human psychological processes; and it is not clear how fully the techniques can be applied to man's capabilities and limitations. The purpose here, however, is not to discuss information theory but to suggest applications it may have to the matter of coding and symbology.

Shannon and Weaver (1949), two early information theorists, propose that there are three levels to be considered in the coding of information:

- Technical - How accurately can the symbols be transmitted?
- Semantic - How accurately do the symbols convey the intended meaning?
- Effective - How effectively does the received meaning affect performance in the desired way?

They advance the idea that a code can be evaluated on the basis of the success with which it operates on these three levels.

A slightly different approach is that of Foster (1964). Citing Miller (1956), Crumley, *et al.,* (1961) and Garner (1962), she points out that information is measured from the point of view of the interpreter, in terms of his uncertainty and the degree to which his uncertainty is reduced. Foster says that there are two principal effects of information coding which should be considered - the human sensitivity to various coding dimensions and the loss and gain of information which results from filtering and categorizing through coding. Since the purpose of coding is to convey to the display user some information about the real world, Foster indicates that there are three basic interactions to be considered.

1. <u>Coding and the Real World</u> - This includes the relation between coding and information content, the human sensitivity to various coding dimensions, the type of transformation from the real world to

the display, and the directness of the relationship between the display and the real world.

2. Coding and Information Processing Tasks - This involves, singly or in combination, search, identification, memory storage and retrieval, and integration of information.

3. Subject Variables - Among these are such individual characteristics as the interpreter's experience, his set, and his strategy or way of structuring the information.

Foster's analysis, while not offered as a theory, does seem to provide a comprehensive and useful paradigm of display coding. It summarizes the relevant variables of coding and provides a guide line for the evaluation of particular coding techniques. The relationship between coding and the operator's tasks is discussed below. The relationship between coding and the real world will be taken up in a later part of this chapter dealing with the display framework or reference system.

Partial confirmation of Foster's analysis is to be found in the earlier work of Sampson and Wade (1961), who describe a trichotomy of observer tasks: *location, recognition,* and *interpretation.* The latter category apparently subsumes Foster's memory storage and retrieval and information integration tasks.

Baker and Grether (1954) approach the classification of operator tasks in a different way. They categorize the indicator (display) in terms of the use which the operator makes of it:

> *"In designing any type of visual indicator it is of utmost importance to consider the ways in which the operator will use the information being presented. This will normally require an analysis of the types of action the operator will be expected to take during or after his viewing of the indicator. Generally, the use of any indicator can be classified on the basis of one or more of the following categories.*
>
> *Quantitative reading: Reading to an exact numerical value.*
>
> *Qualitative reading: Judging in a qualitative way the approximate value, the approximate deviation from a normal or desired value, and the direction from a normal or desired value.*

> *Check reading: Verifying that a normal or desired value is being indicated.*
>
> *Setting: Adjusting an indicator to a desired value, usually to an exact numerical value, or to match another indicator.*
>
> *Tracking: Intermittent or continuous adjustment of an instrument to maintain a normal or desired value (compensatory tracking) or to follow a moving reference marker (pursuit tracking).*
>
> *The first three of these categories, quantitative, qualitative, and check reading, refer to the reading of the instruments without consideration of the type of control over the readings. The remaining two categories refer to the way in which the operator will control the instrument settings. Any single instrument will usually be used in more than one of the categorized ways."*

Still another way of looking at the problem of information coding is from the viewpoint of human cognitive processes, *i.e.*, human information handling capacity. In this connection information theory offers some useful insights. Miller (1956) suggests that in terms of absolute judgments man can identify seven, plus or minus two, steps within a single dimension or attribute. To increase human channel capacity it is necessary to require relative rather than absolute judgments, to increase the number of dimensions along which a stimulus can vary, or to sequence the task so that a series of absolute judgments can be made. Alluisi *et al.* (1957) indicate that information is transmitted faster when code alphabets are restricted to a few symbols; their suggested number was six. In conversation with the authors in August, 1967, Dr. J. Michael Naish of the Douglas Aircraft Company suggested that four or five symbols, comprising about seven dimensions of information, would be the maximum usable number for a head-up display. His emphasis for head-up displays is on an efficient and simplified presentation that does not unduly obscure the real world.

The information handling capacity of the human observer was summarized by Muller and his colleagues (1955) as follows:

> "1. *Man's average channel capacity varies from about 3 to 6 bits per second when the number of symbols in the alphabet is no more than 10 or 12, when the symbols occur in random sequences, and when each symbol*

must be read or responded to in sequence.... Channel capacity also varies as a function of the type of response required in transmitting information, and as a function of the type of coding system used.

"2. *Information transmission rate increases as the size of the alphabet is increased (at least over the range from 2 to 32 symbols). However, as alphabet size is increased (i.e., as each symbol carries more information) the number of symbols handled per second decreases.*

"3. *Man's information transmission curve shows a nearly one-to-one relation with input rate up to a point near channel capacity. This is followed by a rapid drop in output rate with further increase in input rate. Extreme losses in transmitted information result when the input rate exceeds an individual's optimum point...In a self-paced task each individual tends to work very close to his own optimum rate.*

"4. *Man's information handling capacity varies by a factor of two or three as a function of the specific coding alphabet and readout system employed, i.e., as a function of symbol-readout compatibility.*"

To be fully adequate, a theory of information coding should indicate not only what is to be measured but also what units of measure are to be used and how these measurements are to be made. It must consider the entire heirarchy of pilot tasks, not merely E/O display content. It is obvious that *perceptual goodness*, *level of abstraction*, *directness of real world relationship*, and *channel capacity* are not easy things against which to set a yardstick. The literature has very little to offer on this aspect of coding. Neither Gestalt theory nor information theory seem to be sufficiently developed in respect to this problem to be of immediate practical help. Therefore, a usable theory of information coding must be left as an open question until further research and theoretical work have been done.

Even supposing standards and methods of measurement are found, a final question remains. How good is good? For example, the usual method of judging human sensitivity to a particular coding technique is to measure the speed and accuracy of observer performance. Findings relating to the speed of performance are fairly easy to evaluate by comparing them with the speed of operator performance required by the system in which the display is used. System criteria, while not a simple or an easy standard

to apply, at least do afford an objective and usually available means for judging the adequacy of the speed of operator response using a given code technique. But what about accuracy? Reading errors not exceeding 1 to 5 per 100 trials are usually considered acceptable. Honigfeld, for example, cites a report (Office of Naval Research 166-1-105, November, 1949) which offers the criterion of 95% accuracy in responding to a code as agreed upon by a number experts in the field. In some circumstances, this figure is probably usable; but, if an error of response leads to misdirection or loss of control of an aircraft, 95% is clearly not good enough. In fact, an accident rate of 1 per 1,000 landings, if attributable to errors of display reading, would be cause for the most serious investigation by the military service concerned and would probably result in severe censure of the designers of such a display. Here, then, is one area in which further research seems called for. The determination of realistic accuracy requirements, in relation to the conditions of use, and the comparative evaluation of coding techniques in light of these requirements are topics that should be given high investigative priority.

To summarize, the theories of information coding have not yet reached a point of definition and precision where one can predict from them the usefulness or suitability of a particular coding technique. They do, however, identify the classes of relevant human variables and indicate the interactions among these variables. Several investigators have developed schemes for classifying and describing the variables of information coding, of which Foster's seems to be the most comprehensive. In general, the selection of a code involves:

1) consideration of human sensitivity to the various coding stimuli;

2) consideration of the user's task either in terms of his perceptual processes or in terms of the use he makes of the display;

3) consideration of the real world situation which is to be encoded and the way in which the coding scheme symbolizes the real world and permits the observer to perceive real world relationships.

Information theory also offers some useful guide lines both with respect to the number of coding dimensions that can be used simultaneously and with respect to the number of absolutely identifiable steps within a given dimension.

At a more practical level, there is a large body of empirical evidence to guide the designer in the selection of coding techniques. Thus, we are in a position to know what works even though, for the present, we are not completely sure why it works. A summation of the more important research findings in this area is presented in the next section.

CODING DIMENSIONS

The impetus for most of the research in coding techniques has come from the need to develop symbols suitable for radar scopes such as PPIs or tactical situation displays. The basic problem in radar symbology is to find methods of encoding targets along several dimensions simultaneously in a compact and readily identifiable way. The literature is replete with reports of investigations on this topic, and there are several excellent surveys of the findings, notably Muller *et al.* (1955), Sampson and Wade (1961), and Honigfeld (1964).

Unfortunately, most of this literature has only limited application to the problem of E/O display symbology, especially vertical situation displays. There are several reasons for this, all stemming from the differences between display types. In radar displays a major problem is detection of targets against cluttered backgrounds and noise; in E/O displays the symbols are usually generated synthetically, which permits better contrast and the filtering out of noise. In general, E/O displays have fewer, bigger, and more widely spaced symbols than radar displays. The pilot of an aircraft, unlike a radar operator, is not so concerned with target position and vector as with correlating various indices of system dynamics. The pilot, through the aircraft control system, has much more influence on the position and movement of the symbols on his display than does the radar operator who is a more or less passive observer of independently maneuvering targets. The list of differences could be continued, but these few will serve to indicate the degree of dissimilarity between the two types of displays and the need for caution in applying radar research findings to E/O display symbology.

Perhaps an additional, more concrete example will underscore the point. A glance at studies such as Baker and Grether (1954) or Honigfeld (1964) shows that considerable attention is given to blip diameter, wheel, and inclination codes. None of the E/O displays analyzed in the previous chapter and no other direct view or head-up display which we know of makes use of any such type of symbology. Furthermore, it is rare to find an E/O display with anything near the variety and complexity of symbology as one customarily finds on radar displays. Therefore, the following treatment of coding dimensions will by-pass much of the literature on radar symbology and concentrate on those coding techniques which seem to have the greatest value for E/O displays, especially vertical situation displays.

Size

There are two basic questions in relation to symbol size. How large must a symbol be, either minimally or optimally? And, how useful is size as a coding dimension?

The answer to the first question is fairly straightforward, and this is one area where radar symbology research is helpful. Most sources agree that under good viewing conditions and at distances between 15 and 30 inches, the minimum visible symbol size is about 5 minutes of arc. This size, however, is adequate only for detection and perhaps gross recognition tasks. Allowances must be made for more demanding visual tasks and for viewing conditions which are less than good. Poole (1966) suggests that the minimum size be increased by a factor of 3 to obtain minimum *usable* symbol size and that the resultant value be multiplied again by 2 if image quality is poor or if fatigue is a factor. He concludes that a symbol size between 15 and 30 minutes of arc be considered the minimum for all viewing tasks throughout a broad range of conditions. At a distance of 28 inches this means that symbol size should be between 0.12 and 0.24 inch, which accords reasonably well with the findings of Dardano and Stephens (1958) who recommend 3/16 to 5/16 (0.19 to 0.31) inch as a minimum size. At about the same viewing distance, Bowen *et al.* (1959) give 0.06 to 0.30 inch as the minimum satisfactory size. The former value applies under average viewing conditions, and the latter under poor conditions, which are defined as brightness less than 5 millilamberts or contrast less than 50 per cent. Honigfeld (1964) specifies that symbols should be 0.4 inch or larger for a viewing distance up to 7 feet. Steedman and Baker (1960) found a value of 12 minutes of arc to be appropriate for a visual recognition task. Their experiment took into account poor image quality but not variations in lighting conditions. If we use the correction factor of 3 suggested by Poole, the results of Steedman and Baker fall fairly well in line with the others.

It would appear, then, that a symbol size of at least 15 minutes and more likely 30 minutes of arc is acceptable for standardization. At a viewing distance of 28 inches, 30 minutes is equivalent to 0.24 inch; at 18 inches it is equivalent to 0.16 inch. It should be noted that the dimension of the symbol to which this value is to be applied is the diameter for a circle, the length of a side for a square, the length of the longer side for a rectangle, and the height or base of a triangle (whichever is less). For symbols of more complex shape the appropriate dimension of the simple figure (circle, square, rectangle, or triangle) which most closely approximates the shape of the symbol should be used. Note also that the above values do not apply to alphanumeric symbols, which are discussed later under a separate heading.

As a coding dimension, size is relatively poor. Several sources estimate that the number of absolutely identifiable steps is on the order of four of five. For example, Reese *et al.* (1953) indicate that the number of

errors begins to increase significantly if more than five steps are employed, and four steps are the maximum usable if errors are to be kept below 5 percent. Baker and Grether (1954) state that five is the maximum usable number of steps. Poole (1966) indicates that, while it may be possible to recognize more than four size levels, four should be considered the maximum number because of the limitations of symbol generation and display size and because size levels beyond four are likely to result in large, unwieldy, and cluttersome symbols. As a personal observation, the authors feel that E/O displays should not rely on size coding for any significant variable, especially one which is continuous or which extends over a large range of values. This does not apply to displays where size is used relatively, as in some contact analog displays where ground elements grow in size as altitude decreases. Here size is not being used as a discrete or quantitative indication of altitude but rather as a supplementary cue in the general representation of contact flight.

If size is used to encode four or so discrete changes of state for a variable, it is recommended that the scheme proposed by Baker and Grether (1954) be followed. In order to create a scale on which all steps are equally identifiable, they suggest that individual values be selected so that they are equally spaced on a logarithmic scale. Taking their example, if five steps are to be used and the area of the largest symbol is 100 times greater than the area of the smallest, the progression of areas would be 1, 3.2, 10, 32, and 100. Using line length as a code, a four step scale in which the largest and smallest were in the ratio of 10 to 1 would have intermediate steps of 2.2 and 4.6.

Shape

Of all the coding dimensions shape is probably the most widely used for E/O displays because of the many advantages it offers. Human sensitivity to shape differences is quite high, which permits a relatively large number of steps or information states to be encoded. Shape is a major aid to recognition either when used pictorially to create representations of objects in the physical world or when used symbolically to stand for abstractions or qualities which are not three-dimensional. Shape is also one of the coding dimensions which is most readily adaptable to presentation of quantitative information. Consider, for example, the advantages of a circle and a rotating radial line to indicate time in comparison with coding methods such as size, color, brightness, or pulse frequency. Providing display resolution is good, shape coding has the further advantage of requiring very little space, thus permitting high information density without symbol interference or overlap.

Most research on this topic has centered around determining the most discriminable shapes and the most compatible combinations of shapes. Casperson (1950) studied the relative discriminability of six shapes and attempted to relate discriminability to three quantifiable geometric properties:

maximum dimension, area, and perimeter. He found that, regardless of the measure used, the triangle, cross, and rectangle were consistently superior to the star, diamond, and ellipse except when the ellipse became a circle, in which case it ranked third. Casperson also found that increasing any of the three measures increased that probability of a shape being seen and recognized.

These results are somewhat at variance with the findings of Sleight (1952), who asked subjects to sort 126 items, 6 examples of each of 21 different geometric forms. Provided the maximum dimension was 10 minutes of arc or more and contrast and definition were near optimal values, the forms which were most quickly and accurately identifiable were, in order: swastika, circle, crescent, airplane, cross, and star. Rectangles and triangles ranked eighth and tenth respectively. Gerathewohl (1953) compared the relative discriminability of four shapes under noisy conditions and found that the triangle was the easiest to recognize followed by the square, circle, and cross, in that order. Honigfeld (1964) describes a study by Harris *et al.* (1956) which used more complex shapes on a special CRT. They reached the conclusion that variations of a single geometric form, such as sets of round, pointed, and triangular characters should be avoided.

Bowen *et al.* (1959) conducted a similar study to determine the optimum symbols for radar displays. Of the 20 shapes examined, they determined that the best combinations of five symbols were either 1) rectangle, circle, zigzag (Z), cross, and semicircle or 2) cross, semicircle, ellipse, triangle, and square. They also concluded that relatively few shapes should be used, especially under adverse display conditions, where the number should not exceed six.

The foregoing studies and other related research are discussed in Honigfeld (1964), who offers the following guidelines for shape coding.

> "1. *The circle, rectangle, cross, and triangle are the most distinctive geometric forms.*
>
> 2. *Squares, polygons, and ellipses are discriminated poorly; they should be avoided.*
>
> 3. *Variations of a single geometric form....should be avoided.*
>
> 4. *Unique symbols (e.g., swastika, anchor, flag, rocket, airplane) are good in specific situations.*
>
> 5. *Symbols should be few in number and under adverse display conditions should not exceed six.*
>
> 6. *Symbols 0.4 inch or larger are best for viewing up to seven feet.*

"5. Symbol meanings should be compatible with their conventional, stereotypic meanings."

Much of the research cited above deals with shape coding for radar displays. It is, however, applicable to the design of any display which makes use of synthetic (computer-generated) symbology so long as the designer is more or less unconstrained by the needs of pictorial realism in assigning correspondences between symbol shape and meaning. This is usually the case with horizontal situation displays of tactical information. The displays of the existing Naval tactical data systems (NTDS, ATDS, and MTDS) are examples where this freedom of selection of shape-meaning relationships obtains. A standardized symbol alphabet which makes extensive use of shape coding has been developed for these systems, and this alphabet seems generally consistent with the research findings and design principles enumerated above. Thus, in the case of Naval tactical information displays it would appear that the basic research has been done and that the results have been successfully applied to the shape coding of symbols for operational systems. A report by the Air Standardization Coordinating Committee of NATO (1964) outlines a standard alphabet of shapes which could apply to virtually all tactical information displays of air, surface, and subsurface targets. There seems to be little need for further basic research in this area; effort should be concentrated on widening the application of the existing symbology.

The same degree of certainty does not exist, however, for navigational displays and vertical situation displays. For both kinds the designer must give attention to more than just the relative discriminability of symbol shapes. In the case of a map display he must consider the relationship of the shape to the geographic and cartographic features he is trying to represent. That is, the symbolic array must conform to what the operator would see as he looked down on the earth or as he looked at an aeronautical chart. The need for correspondence between electronically generated symbols and the conventional cartographic symbols is a particularly vexing problem, and there is growing concern about the compatibility between the symbols now used on printed maps and those which can be drawn electronically on navigational HSDs. (See JANAIR, 1966, for a discussion of this problem.) More research is needed to determine fully the specifics of shape coding geographic information for map displays. The selection of shapes for non-geographic symbols (e.g., present position, course, or ground track) should be guided by the general principles set forth earlier.

For vertical situation displays the selection of symbol shape also depends on factors other than discriminability. For those symbols which represent real world objects, pictorial realism is of great importance. That is, the symbol which represents the earth on a VSD must be planar or rectangular since this is how the earth appears when viewed through the windshield. Similarly, the runway or landing site symbol must correspond in shape to the outline of its real world counterpart, i.e., the symbol must be a

triangle or a trapezoid. Thus, the designer's repertory is constrained not only by the shape of the things he must represent but also by the laws of perspective which govern how these things will appear in projection upon a vertical situation plane.

A second kind of limitation on the selection of symbol shapes arises from the fact that the E/O display is located within a larger display complex, the instrument panel, and is often used in conjunction with these other instruments. The shape of a symbol may thus be influenced by the way in which similar information is displayed on conventional instruments. If, for example, a VSD is to contain altitude information and this same information is presented on a tape gauge elsewhere in the cockpit, the designer may choose for the VSD a symbol whose shape suggests a scale and a pointer in order to facilitate cross-checking of the two altitude indicators and to conform with user experience with more conventional forms of altitude presentation. Likewise, the nature of the information to be presented may influence the choice of symbol shape. In the example of the altitude display just used, it would also be possible to justify the selection of a scale and pointer symbol on the grounds that what is being shown is a continuum and the symbol shape must permit the operator to identify his position within that continuum in relation to certain discrete points. While these remarks are somewhat far afield from the basic question of the usefulness of shape as a coding dimension for displays, they have been introduced to illustrate how coding is inextricably bound up with other aspects of display design and how care must be exercised in applying the findings of basic research studies.

To summarize, extensive research has been done on the relative discriminability of shapes and the use of shape coding. This work is of value, but it must be tempered by considerations such as the need for pictorial realism, the use to which the symbol or the information is to be put, and conformity with other display conventions. The exact number of shapes which can be accurately discriminated is not known, but it is certainly large enough for normal display requirements, and shape coding should be regarded as one of the major resources of the display designer. It should be noted that the discriminability of a shape tends to increase with the size of the symbol (Casperson, 1950; and Gerathewohl and Rubinstein, 1953). Therefore, the more important it is to recognize a given shape, the larger the symbol ought to be. For tactical information displays the basis for a standard shape code already exists. Standardization of symbol shapes for map and vertical situation displays is somewhat farther off. The application of research findings to the design of certain VSD and HSD symbols is taken up at the end of this chapter.

Alphanumerics

Of all the coding techniques, alphanumerics has attracted the greatest attention because letters and numerals offer almost limitless possibilities for encoding information. The optimum characteristics of alphanumeric codes for various applications have been the subject of intense investigation over the years, and nearly half of the research reports ever published on symbology deal with some aspect of alphanumerics. We will not recapitulate the findings here since several excellent summaries of the research literature are readily available. The best of these is a reference handbook recently published by Cornog and Rose (1967) which includes resumés of over 200 studies on alphanumeric symbols. We recommend it highly to the reader who wishes to pursue this subject in detail.

In the 1950s research on the design of alphanumeric characters for aircrew station displays led to the font called NAMEL which has been standardized by the armed services in MIL-M-18012 and MS 33558. See Figures 14 and 15. MIL-M-18012 applies to transilluminated and non-transilluminated letters and numerals for aircrew station displays and control panels; MS 33558 covers numerals and letters for aircraft instrument dials. The major provisions of MIL-M-18012 for transilluminated alphanumerics are listed in Table 17. The MIL-M-18012 dimensions are based on a 28-inch viewing distance. To assist in the conversion to other viewing distances, the equivalent in angular measure is given in parenthesis below each linear dimension.

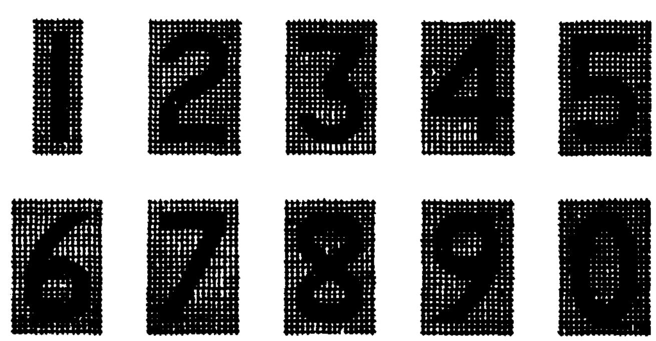


Figure 14. MIL-M-18012 NUMERALS

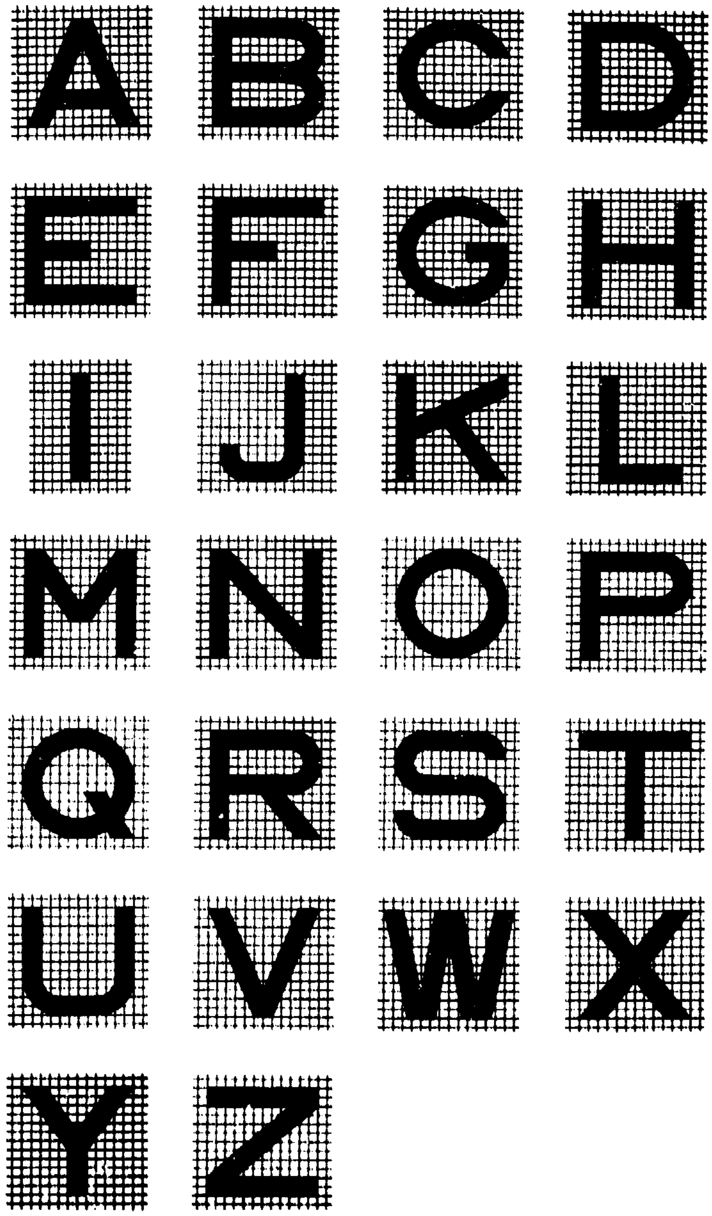


Figure 15. MIL-M-18012 LETTERS

TABLE 17 - MIL-M-18012 NUMERAL AND LETTER DIMENSIONS

DIMENSION	NORMAL USE		FOR EMPHASIS	
	TYPE I WHITE ON BLACK	TYPE II WHITE ON GRAY	TYPE I WHITE ON BLACK	TYPE II WHITE ON GRAY
Height (H)	0.125 - 0.141" (15 - 17 min.)	0.156 - 0.172" (19 - 21 min.)	0.156 - 0.172" (19 - 21 min.)	0.188 - 0.204" (23 - 25 min.)
Width				
Numerals				
1	1 SW	1 SW	1 SW	1 SW
4	50 - 80% H	60 - 80% H	50 - 80% H	60 - 80% H
others	40 - 70% H	60 - 70% H	40 - 70% H	60 - 70% H
Letters				
I	1 SW	1 SW	1 SW	1 SW
J, L	50 - 75% H	70 - 90% H	50 - 75% H	70 - 90% H
W	70 - 110% H	80 - 110% H	70 - 110% H	80 - 110% H
others	60 - 100% H	80 - 100% H	60 - 110% H	80 - 100% H
Stroke Width (SW)				
Numerals	0.013 - 0.020" (1.7 - 2.3 min.)	0.020 - 0.025" (2.3 - 3.0 min.)	0.013 - 0.020" (1.7 - 2.3 min.)	0.020 - 0.025" (2.3 - 3.0 min.)
Letters	0.018 - 0.025" (2 - 3 min.)	0.025 - 0.030" (3 - 4 min.)	0.018 - 0.025" (2 - 3 min.)	0.025 - 0.030" (3 - 4 min.)
Spacing				
Between letters and numerals	1 SW	1 SW	1 SW	1 SW
Between words and numeral groups	1 standard charact. width	1 standard charact. width	1 standard charact. width	1 standard charact. width

The MIL-M-18012 alphanumeric design has been proven acceptable for use on instrument dials read in reflected light and on transilluminated panels, but E/O displays are neither of these. E/O display symbols are somewhat like transilluminated characters in that both are light-emitting, but E/O displays are luminescent not incandescent. Further, transilluminated characters are made up of solid translucent areas whereas E/O display characters are not. In the case of raster video, they are made up of closely spaced lines, usually horizontal; on line-written displays they consist most often of short straight line segments. Thus, the technique of generation will influence not only the shape, but the size and stroke width of E/O display characters. The purpose of the following discussion, then, is to examine the applicability of the provisions of MIL-M-18012 to alphanumerics generated by electronic techniques.

Rowland and Cornog (1958) and Moore and Nida (1958) were two of the earliest studies to investigate the legibility of various printing fonts on televised displays. This led to the design of a new font known as Courtney, which was deemed to be more suitable for closed-circuit TV displays. The chief features of this design, which was to be read at distances up to four feet, were a symbol height of 0.375 inch (27 minutes of arc at 48 inches), a width-to-height ratio of 3:4, a vertical-stroke-width-to-height ratio of 1:5.33, and a horizontal-stroke-width-to-height ratio of 1:4. Serifs, nulls, offset, and cutoff were used as appropriate to eliminate orientation confusion. In a follow-on study Moore and Nida (1958) found that with an 875 instead of a 625 raster line system character height could be reduced to 0.25 inch and retain legibility at four feet. They also found that while a five raster line character height was a theoretical minimum, a height of nine to ten lines was a more practical standard. In later studies Seibert *et al.* (1959) and Seibert (1964) found that the minimum acceptable symbol height was 12 - 15 minutes of arc and that vertical resolution should be between 8 and 12 lines. A 1966 study by Shurtleff and Owen cast doubt on the superiority of the Courtney font over the standard Leroy font (which is similar to the MIL-M-18012 font) and a revised Leroy font of their own design. However, Shurtleff and Owen did confirm that vertical resolution on the order of 8 to 10 lines was minimal if symbol size was to be kept at about 15 minutes of arc.

In 1967 Shurtleff published a review of the literature on the legibility of TV symbols. In it he surveyed the extensive work done by him and his colleagues at the Mitre Corporation and evaluated some 100 other research reports dating back to 1941. Since the findings of our own literature view and our own personal views agree largely with Shurtleff's, we shall - in the interest of brevity - simply summarize the major points of his article.

1. For 98 - 99 per cent accuracy of identification, vertical symbol size must be between 8 and 12 lines per symbol height (Seibert *et al.* 1959), a minimal resolution of 10 lines being recommended for systems applications (Shurtleff and Owen, 1966).

2. Visual sizes required for 99 per cent accuracy vary from about 13 minutes of arc for a resolution of 10 lines to 36 minutes of arc for 6 lines. (Shurtleff *et al.*, 1966b)

3. Accuracy and speed of identification with TV raster symbols are as good as with solid-stroke symbols if the active element of the raster is twice the width of the inactive element. (Botha and Shurtleff, 1963b)

4. The quality of interlace is not a major factor in accuracy of identification. (Elias *et al.*, 1964; Elias, 1965; Shurtleff and Owen, 1966)

5. There is little difference between bandwidths of 2 and 4 mc. for symbol resolutions from 6 to 18 lines per symbol height and for visual sizes ranging from 3 to 15 minutes of arc. Bandwidths less than 2 mc. are undesirable. (Siebert, 1964) The utility of bandwidths greater than 4 mc. was not studied.

6. The visual size required 99 per cent accuracy is about 11 per cent greater for symbols at the edge of the raster than for symbols at the center. (Shurtleff *et al.*, 1966b)

7. The critical viewing angle at which significant inaccuracy of identification begins to occur is between 19 and 38 degrees from a normal line of sight. (Seibert *et al.* 1959)

8. For intermediate values of symbol and background brightness the direction of contrast (light on dark or dark on light) is not a major factor in legibility. (Seibert *et al.*, 1959; Kelly, 1960)

9. Angular scan orientation has no significant effect on accuracy or speed of identification. There are only slight differences when scan lines are oriented 45 degrees to the base of the symbol as compared to when they are parallel to the base of the symbol. (Shurtleff *et al.*, 1966a)

10. Specially designed symbols seem to be no better than those of conventional design. Therefore, standard Leroy symbols are recommended for television displays because of their familiarity, ease of construction, and greater availability. (Shurtleff and Owen, 1966)

To Shurtleff's last point we would add that, in view of the similarity between Leroy and MIL-M-18012 characters, MIL-M-18012 also seems to be suitable as a standard font for televised displays, or at least as a goal toward which display designers should work.

The values for symbol height in visual angle cited by Shurtleff are reasonably close to those specified in MIL-M-18012 for transilluminated alphanumerics-- 13 - 15 minutes in Shurtleff *vs.* 15 - 17 minutes for white on black and 19 - 21 minutes for white on grey. For raster and line-written direct view displays we recommend, therefore, that the minimum height for alphanumerics be 15 minutes of arc if good contrast can be preserved. If not, 21 to 25 minutes of arc should be specified as a minimum. For raster displays, size should also be specified in terms of the number of lines per symbol height. That is, under good contrast conditions, vertical symbol height should be 15 minutes of arc or 10 raster lines, whichever is greater. Under poorer conditions of contrast vertical symbol height should be 21 to 25 minutes of arc or 16 raster lines, whichever is greater. Since these values are not fully supported by empirical evidence, we further recommend that research be undertaken to verify their appropriateness.

As to character font, stroke width, and width-to-height ratio, we also conclude that MIL-M-18012 is suitable as a goal for E/O displays so long as allowances are made for departures from this norm due to the techniques of generation and the vertical and horizontal resolution of the display system. We have found very little evidence to indicate how much degradation in form and proportion is tolerable. We suspect that legibility will vary not only with symbol font, but also with such conditions of use as the amount of alphanumerically coded information, the operator's familiarity with the numeral and letter combinations, and the degree to which he can anticipate the occurrence of given statements. Here, too, we believe it is preferable to test these hypotheses through empirical studies.

For head-up displays the situation is much less clear. We have found almost no research that pertains to the legibility of head-up display alphanumeric symbols. Our own experience indicates that symbol sizes on head-up displays should be somewhat larger than on direct view displays in order to ensure that the symbols will be visible against variegated and high brightness backgrounds. Symbol sizes of 25 to 35 minutes of arc are commonly found on contemporary head-up displays. With the increased symbol height comes a consequent reduction in stroke-width-to-height ratio, often to 1:10 or 1:15. The result is a rather thin, spidery font which lacks the bulk, and perhaps some of the qualities of good visibility, found in alphanumerics on direct view displays and on conventional aircraft panels and instruments. However, we know of no reports which actually demonstrate that such is the case.

The shape of head-up display alphanumerics is likewise a subject of concern among display designers and users. Head-up displays tend to be line-written displays, on which alphanumeric characters are generated by matrices of short straight line segments or strokes. With present stroke generators curved lines are hard to achieve. The most common technique is to generate characters from a box figure-8 matrix, if only numerals are required. If letters are also required, a more complex matrix must be used. One such is that proposed by Cohen and Webb (1953), which makes

use of the matrix shown in Figure 16. Cohen and Webb found that if MIL-M-18012 alphanumerics were not attainable, this font gave satisfactory results after a short period of training and practice. Another font is that developed for the numerals on the F-111B head-up display, which makes use of a digital-matrix symbol generation technique. These numerals are made up of relatively small line segments (about 1.5 minutes). When combined into symbols, these segments give reasonably good approximations of curved lines and can be used to create a font similar to that of MIL-M-18012. The numeral 3 written with each of these matrices and the MIL-M-18012 numeral 3 for comparison are shown in Figure 16.

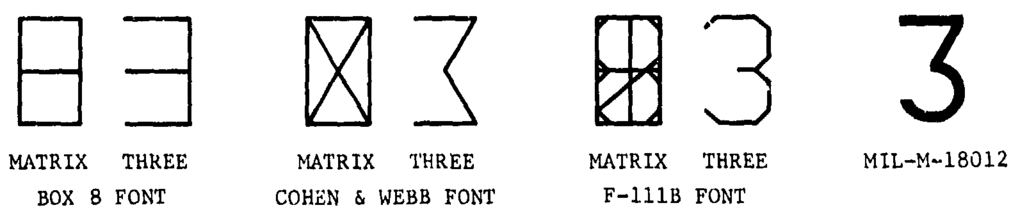


Figure 16. TYPICAL STROKE-WRITING ALPHANUMERIC SYMBOL MATRICES

We do not believe that the techniques of alphanumeric generation for head-up displays have yet reached a point of development where standardization is feasible. We recommend that the design and testing of letter and numeral fonts suitable for head-up displays be given high priority. As a tentative, interim arrangement we suggest that a minimum symbol height of 30 minutes would be satisfactory and that MIL-M-18012 be used as a guide for symbol font design, even though deviations are to be expected and should be tolerated.

Color

Color is generally recognized as an excellent coding dimension. It commands attention and greatly facilitates search and recognition tasks. In some circumstances it has been demonstrated that color enhances performance in interpretation, reading, and higher cognitive tasks. Color lends itself readily to combination with other types of codes, especially geometric and alphanumeric. All in all, color seems to offer great promise for use in E/O displays.

In a series of studies (1962, 1963, 1965) Smith and his colleagues investigated the effects of color on a variety of visual tasks. They found that, while the use of color significantly reduced search time, neither

the particular colors of the target and the display background nor the direction of color contrast had any appreciable effect. An almost identical conclusion was reached by Brooks (1965), whose study showed that there was a significant difference in search times only between a colored and a monochromatic display. For multicolored displays, Smith (1962) found that when the subject knew the color of the target in advance, search time was shorter than when he did not. When the color of the target was unknown, search time was about the same as for a monochromatic display. For a slightly more complex task, counting all the displayed items of a particular class, Smith (1963) again found that color coding measurably improved performance. In a subsequent study (Smith *et al.* 1965a and 1965b), subjects were required to perform row-comparison and item-counting tasks on a display consisting of two-digit entries arranged in a tabular matrix. Color coding resulted in an average reduction in counting time of 72 per cent and a decrease in error frequency of 86 percent, where the display format was not related to the task. For row-comparison color coding produced reductions of 47 per cent in counting time and 43 per cent in error frequency. While the tasks in this last study were perhaps not typical of those for a flight or navigation display, the results do suggest that color coding is a significant aid for a broader range of tasks than just target detection and recognition.

Partial confirmation of this assertion can be found in the work of McLean (1965), who investigated the effects of color and brightness contrast, direction of contrast, and contrast values upon the legibility of a circular dial. He found that the addition of color contrast to a dial of given achromatic brightness contrast, with a light on dark direction of contrast, could improve the legibility of the dial. Legibility was also found to increase as color contrast increased. McLean concluded that color might have a wider application as a coding technique in complex system displays than previously supposed.

Honigfeld (1964) reports a study by Hitt (1961), who examined the effectiveness of color in comparison with other coding dimensions: numeral, letter, geometric shape, and configuration. Hitt found that searching and recognition are two independent task factors and that color and numeral codes were superior to the others. Further, if correct recognition of symbols is more important than reducing search time, numeral coding is superior to color coding. Honigfeld also cites a study by Newman and Davis (1961), who examined color coding as a means of reducing the number of symbols on a display. Results indicated that symbol-plus-color coding was superior for the tasks of locating and decoding compound symbols. From this and similar evidence Honigfeld concluded that

> "*Color is a superior coding dimension when the operator must simply locate targets. When he must also identify targets, however, color is most useful when combined with other symbols, such as numerics or geometrics.*"

A great deal of research effort has also been devoted to establishing the number of different colors which can be used together effectively. In general, the number of colors (spectral hues) which can be identified depends upon the brightness and size of the light source, the nature of the observer's task, and the particular colors used. If only relative judgments are required, *i.e.*, if the observer is asked only to tell whether two simultaneously presented color stimuli are the same or different, the number of discriminable spectral hues is quite large. Rizy (1965) cites an unpublished report by Halsey (1962), who estimates that under ideal conditions the total number may be as high as ten million. However, Halsey continues, under poor observing conditions and considering stringent speed and accuracy demands made on the operator as well as the realistic limitations imposed by operational color generating equipment, the number of discriminable colors may be as low as three.

Most experimenters prefer to use absolute judgment as the criterion of discriminability. That is, the observer is presented with a single stimulus which he must identify by name without reference to a standard. Baker and Grether (1954) advise that, if the source has a brightness of at least 1 millilambert and subtends at least 45 minutes of arc, the ten hues shown in Figure 17 can be correctly identified nearly 100 per cent of the time.

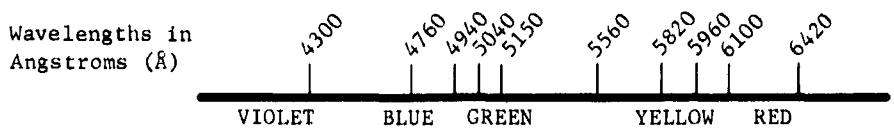


Figure 17. TEN ABSOLUTELY IDENTIFIABLE SPECTRAL HUES
(Adapted from Baker and Grether, 1954)

If white is included, the number of absolutely identifiable hues is eleven. Several other sources, Halsey and Chapanis (1953), Muller *et al.* (1955), Morgan *et al.* (1963), and Poole (1966), concur with this estimate.

However, some investigators caution that while ten (or with white, eleven) may be a maximum number, the number usable for a color code is probably somewhat fewer. Conver and Kraft (1958) found that five to eight were the most that could be used for coding purposes. Earlier, Muller *et al.* (1955) had recommended that care should be exercised when using color for more than four or five coding categories. Their reasons for advising caution were as follows:

> "*The apparent color of an object is a function of numerous factors, including the distribution of the energy that is transmitted from the object to the*

eye, the nature of the background against which the object is viewed, and the state of adaptation of the eye. For example, the apparent color of a surface varies with changes in the color temperature of the illumination and with the introduction of other colored objects into the field of view."

These findings and recommendations are only partially applicable to CRT displays, which produce color not by absorption or reflection but by an additive light-emitting process. That is, on CRTs small dots of three primary colors are produced either singly or in combinations to yield various colors. Even though rapid advancements have been made in the development of colored phosphors, the present state of color tube technology limits the number of spectral hues which can be produced on E/O displays. Poole (1966) estimates that the practical limit, given present three-color generation techniques, is about seven. Satisfactory results in achieving up to this number have been obtained under laboratory conditions, but they have not yet been realized for airborne displays under operational conditions. Under field conditions it is still difficult to produce more than four absolutely discriminable hues - red, yellow, green, and blue.

Rizy (1965) points out additional reasons for using care in the application of color research data to color-additive displays.

"The application of color addition to actual coding requirements has its unique constraints. First, by definition, the additive symbol colors must vary not only in hue but in saturation and brightness. Second, any recommendation concerning applying color additive codes to information presentation should take into consideration the nature of the display observer's task, which contains elements of both relative and absolute judgment. Finally, there is no necessity in display-observer interface for equally discriminable symbol colors, but only for seven colors which produce the highest amount of discrimination obtainable."

Our review of the literature has turned up very little data on the relative effectiveness of various colors for coding, and even less that is of specific applicability to CRTs. Using a film projection technique and a three-color (red, green, blue) additive process similar to that of CRTs, Snadowsky *et al.* (1964) found that the relative order of discriminability was red, yellow (red + green), blue, magenta (red + blue), white (red + blue + green), green, and cyan (blue + green). They also found that registration (superposition) of the color images was of critical importance in the recognition of two- and three-color compounds. When misregistration exceeded 65 per cent, *i.e.*, when the constituent color images overlapped by one-third or

less, color recognition was severely degraded. Since the experimental conditions were close to ideal for observation, they further concluded that a misregistration parameter of somewhat less than 65 per cent would be the maximum tolerable in an operational environment.

A later color additive study by Rizy (1965), who was one of Snadowsky's associates in the study just cited, produced somewhat different results. Rizy found that red was superior, followed by yellow, magenta, and white which were statistically equivalent, and finally cyan, blue, and green. The superiority of red is not surprising; the attention-getting value of this color is well known. This may also account for the high rank of magenta, which was made up of red and blue. The high discriminability of yellow can probably be explained, as Rizy suggests, by the nature of the response of the human visual mechanism. The low rank of green is hard to explain since it and yellow are the brightest appearing colors, and green has long been regarded as an excellent color in terms of visibility and discriminability. Rizy suggests that the poor showing of green may be accounted for by the peculiarities of the color generation process and by the tendency of subjects to confuse green and cyan (blue-green).

Apart from these studies, there seems to be very little research which would support the selection of a specific color code or color scheme for E/O displays. One scheme which has been suggested, specifically for direct view VSDs, is the so-called natural scheme of blue for the sky and brown and green for the earth. Command information, such as steering, and status information not directly related to display coordinates (*e.g.*, airspeed or vertical velocity) could be presented in white or yellow. Another scheme which has been advanced is that of the conventional color coding now used for cockpit indicator lights - red for warning, emergency, or danger; yellow for caution; blue for advisory; and green for satisfactory, correct, or go. Just how this could be related to classes of information such as command and status or attitude, airspeed, and altitude is not clear. The opto-mechanical head-up display developed in France makes extensive use of color coding for various categories of information. Attitude, airspeed, altitude, and heading are each presented in a different color to assist the pilot in identifying the various indices which make up the display. We do not know the rationale by which the various colors were selected and assigned to display quantities. All of these schemes are based on convention or nonce arrangements and do not necessarily take into account either human performance variables or the unique properties of color on CRT displays. Further, none of these seem compatible with the use of red light in the cockpit at night.

Because of the relative paucity of experimental evidence in this area and because of the somewhat contradictory results of the few studies that have been done, we conclude that a color standard for E/O displays cannot be specified at this time. Specifically, research is needed to relate color on CRTs to human performance variables and to realistic visual tasks which

the observer ..t perform. Such research should also take into account the problems of ambient illumination, both day and night, and the effects that other light-emitting sources in the cockpit may have on the E/O display. For head-up displays the critical problem is not just the discriminability of colors but the discriminability of colors against the external world backgrounds which may be encountered in operational use. Since it is reasonable to assume that airborne color displays will become a reality within the next three years or so, we urge that such investigations be given a high priority. A further discussion of color as it applies to CRT displays is contained in Chapter V (pages 267 ff).

Motion

The human ability to estimate velocity is extremely poor, especially without an available standard for comparison or without considerable past experience. Even with a basis of comparison, judgments are usually only relative, *i.e.*, faster or slower. In general, estimates of acceleration, the rate at which velocity is changing, are even more inaccurate. For these reasons very little attention has been paid to motion as a coding dimension for displays.

The circumstances in which motion does seem to be of some value are when an object moves against a stationary background or when it moves differently from other elements in the visual field. Since this calls for a qualitative judgment only, the absolute or relative motion of the object may aid in detection or recognition. Such a case is a radar display where the greater speed of airborne targets causes them to stand out from surface targets

Some contemporary E/O displays do make use of motion as a coding dimension. The F-111B displays are one such case. Here all display elements are stationary if all commands have been satisfied and if attitude is stable. The movement of a symbol is, thus, a cue that the status of the aircraft or the command values have changed. The same is true of the attitude and steering elements of most of the other displays analyzed in Chapter III. Some may not consider this a legitimate case of motion being used as a coding dimension since it only serves as an attention-getting device and since other factors such as position and pattern recognition also come into play.

Better examples of motion as a coding technique are the AAAIS and V/STOL displays discussed in Chapter III. On the AAAIS dashed lines which run along the edge of the pathway symbol are used to indicate deviations from command airspeed. (See Table 6.) If the actual speed of the aircraft is less than command speed, the dashed lines move up the display or, because of perspective, away from the observer. The dashed lines move in the opposite sense if actual airspeed is greater than command airspeed. In

both cases the apparent velocity of the symbols is proportional to the difference between command and actual values. The pilot's task is to adjust airspeed so that the dashed lines remain motionless on the display. A similar technique is used on the V/STOL display for landing. (See Table 8.) In this case display elements move up or down the display (away from or toward the observer) to indicate groundspeed and laterally to indicate lateral ground velocity. We have conflicting reports of pilot acceptance of this kind of symbology, and we cannot speculate as to its effectiveness. In general, the success of such a technique will depend upon the scaling and sensitivity of symbol movement and the compatibility of this type of presentation with overall display dynamics.

As a personal observation, we would caution against the use of motion coding on head-up displays. Collimation causes head-up display symbols to appear at optical infinity. This is, of course, not true infinity, and the optical system is in fact focused at some finite distance ahead of the aircraft. The observer's estimate of this distance can be influenced by such factors as the distance to the real world objects seen through the combining glass, collimation errors in the optical system, and the size of display elements in relation to other visible objects. Since estimates of velocity are directly proportional to how far from the observer the object appears to be, any error in range estimation will lead to corresponding errors in velocity judgments. Thus it would appear unadvisable on a head-up display to use a form of presentation which calls for the observer to determine the velocity or acceleration of a symbol as a means of controlling the aircraft.

Flash or Flicker

The possibility of using flicker or flash rate coding has been examined by several investigators over the last twenty years, and all have concluded that flicker is an inefficient coding dimension. Gebhard (1948) recommended that its use be limited to a single on-off pattern for the purpose of attracting attention. Baker and Grether (1954) considered it unsatisfactory because of the high brightnesses required in order to avoid fusion at the higher flash rates. Morgan *et al.* (1963) and Poole (1966) advise against flashing coding because it can be extremely distracting and annoying, especially if there is more than one symbol blinking at any given time. Honigfeld (1964) cites several studies in connection with radar displays. All of these indicate that the number of discriminable steps under ideal conditions is on the order of five and that probably no more than three (4 cps, 1cps, and 1/3 cps) can be used effectively. Honigfeld also notes a series of studies by Gerathewohl which suggest that, within limits, the higher flash rates are more conspicuous than the lower and that subjects tend to respond more quickly with higher flash rates.

Thus, we conclude that flicker codes should be used sparingly on E/O displays and only for the purpose of attracting attention, such as a warning or caution indicator or as a signal that some critical event is imminent. The flash rate should be somewhere in the range of 1 to 4 cps, with the on and off phases of about equal duration. Within this range the flash rate should be selected with the importance of the information or the urgency of response in mind; the more important or urgent the item, the higher the flash rate. Preferably only one blinking signal, and certainly not more than two, should be on the display at any given time. The items selected for flicker coding should be either short-duration or single-occurrence events since it would be extremely distracting to have a blinking signal present on the display for more than a few seconds.

Brightness

Most reference documents on coding give little attention to brightness, which is regarded as a relatively poor coding dimension. Baker and Grether (1954), for instance, believe brightness coding to be unsatisfactory because it results in poor contrast effects and less bright signals tend to be obscured by brighter surrounding signals. It must be noted, however, that they assume a display with a brightness range of 1 to 50 millilamberts, which would yield only three or four usable brightness steps. Morgan *et al.* (1963) reach an almost identical conclusion. Honigfeld (1964) considers brightness of limited applicability as a display variable. She recommends using only two steps - a high level for information of primary interest and a low level for that of secondary interest, again for a display with a brightness range of 1 to 50 millilamberts.

All these sources, however, seem to refer to a line-written display, and they do not seem to consider the shades of gray presentation used on raster video displays as a form of brightness coding. Several contemporary E/O displays use shades of gray raster video successfully, and they typically contain seven to ten steps. The brightness range for these displays, however, far exceeds the 1 to 50 millilamberts assumed by the authors cited above. A brightness range up to 250 foot-lamberts (approximately 270 millilamberts) is not uncommon. Each shade of gray (or whatever color the phosphor may be) differs from the others in terms of saturation and brightness, primarily the latter; and it does not seem to us too difficult to make a case for shades of gray as a form of brightness coding. We do not wish to make an issue of this since the question seems to turn around what kind of display one has in mind when speaking of brightness coding.

In the case of line-written displays the recommendations of the authors cited above are acceptable, and they should be followed. For a map display or for a line-written VSD the background information should be of the lowest brightness consistent with good visibility. Key geographic or aircraft performance features should be highlighted by one brightness level, or at

most two, above the background. For raster displays the situation is much more complex. For recommendations we refer the reader to Chapter V, Display Characteristics, where the topic of shades of gray is taken up in more detail within the larger context of display brightness and brightness contrast.

Compound Codes

Thus far we have dealt with coding as it applies to information which varies only by class or by one dimension within a class. However, it may be necessary or desirable to embody more than one dimension of information within a single symbol or complex, and for this purpose compound coding is appropriate. Compound codes permit a greater density of information within a given display area, but at the price of increasing the complexity of display interpretation and, consequently, the operator's response time and probability of error. If compound codes are used, each constituent must be readable separately without confusion. Also, information must be kept to essentials since combination codes will lose their advantage and efficiency if too much information is portrayed (Honigfeld, 1964).

Several sources (e.g., Baker and Grether, 1954, and Kuehn, 1966) point out that, if compound codes are being considered, two basic rules should be followed.

1. Compound coding should not be used for only one dimension of information when a single code is clearly discriminable. That is, one coding dimension per dimension of information. For example, it is preferable to use shades of gray alone or shape alone to distinguish between command and status indicators on a scale rather than resorting to such combinations as bright triangles and dark rectangles.

2. When two or more dimensions are to be coded, the same number of coding dimensions should be used. That is, do not use one coding dimension for more than one dimension of information. Thus, if the display is to have command and status indicators for airspeed and altitude, use one code for status-command and another for airspeed-altitude. For example, do not use shape alone to encode all of this information (triangle-status airspeed, circle-command airspeed, rectangle-status altitude, cross-command altitude). Rather, use shade to distinguish between command and status and shape for

airspeed and altitude (bright triangle-command airspeed, dark triangle-status airspeed, bright rectangle-command altitude, dark rectangle-status altitude).

Muller et al. (1955) also offer the advice that compound codes may decrease the number of discriminable steps within each of the component coding dimensions. Therefore, they suggest that fewer than the maximum distinguishable number of steps be employed for each coding dimension, when used in a compound code, in order to provide a safety factor.

Bowen et al. (1959) gave the following rules for constructing combination codes of more than one geometric shape. While their advice was directed at the problem of radar symbology, it seems generally applicable to other types of E/O displays.

1. *Primary symbols should be large and enclose a space.*

2. *No auxiliary symbol should cross, distort, interfere with, or in any way obscure the primary symbol.*

3. *Symbol complexes should not normally exceed two geometric symbols or possibly three in some circumstances: a location dot, and a speed and direction vector line where applicable.*

4. *When other information is required, it should be represented numerically (e.g., one, two, or three marks to indicate the magnitude of the object) or in actual numbers and letters.*

5. *The geometric center of the symbol and/or large clear dot should indicate location.*

6. *Auxiliary marks should be compact solid figures.*

Code Compatibility and Meaning

The selection of a code depends on more than just human sensitivity to a particular coding dimension and the nature of the operator's task. The compatibility between the information to be presented and the code selected to convey it is also of major importance. It has been estimated that man's information handling capacity varies by a factor of as much as 2 or 3 depending upon the specific coding alphabet and readout system employed, i.e., as a function of code compatibility. The symbol and the event or

condition symbolized should have a natural relation in that their association should conform to well-established habits or population stereotypes. (Muller et al., 1955) Code compatibility will not only promote speed and accuracy of interpretation, it will also facilitate learning and simplify the training process.

An early, and definitive, statement of what is meant by code compatibility is that of Baker and Grether (1954).

> "*Information may be considered to be quantitative, qualitative, or both. Qualitative information concerns kinds of objects or relationships such as friend or foe, bomber or fighter, etc. Quantitative information concerns the extent of magnitude of an object or relationship such as the speed of a missle, the altitude of a bomber, etc. Methods of coding information can also be considered as quantitative, qualitative, or both. Codes relying on geometric shapes or colors are considered to be qualitative codes because the various colors and various shapes are qualitatively different. Codes relying on size, brightness, length, etc. are quantitative codes because these differences are solely quantitative. Number-codes can be considered to be qualitative or quantitative. Codes are more easily interpreted when qualitative codes are used to code qualitative information and when quantitative codes are used to code quantitative information.*"

For E/O displays, which tend to be pictorial displays, code compatibility is doubly important. Not only should there be compatibility between the code and the information encoded, the display should also represent a familiar approximation to the real world situation. That is, the code should comply with conventional and stereotypic meanings normally associated with such symbols. With an E/O display most observer tasks entail recognition and interpretation of relationships between elements or parts of the total information available. It is important, therefore, that any existing relationships between the symbol and the thing symbolized be used to advantage. This suggests the need for stimulus-response compatibility and the maintenance of relationships between the real and displayed worlds, but it also implies a <u>directness</u> of association between what is represented and its representation. As Foster (1964) points out, this directness of relationship is not always easy to achieve. It may be that there is no coding dimension available, or technically feasible, which has a natural relationship to the information to be encoded. For example, what shape, color, or shade of gray naturally suggests angle of attack? It may also be that the information to be encoded is abstract while the code, by its very nature, is concrete. In such a situation the display designer's task

becomes one of finding a suitable way of presenting the abstract in a concrete form, *i.e.*, as a perceptual (in distinction to a conceptual) dimension. The degree to which a particular situation can be made more concrete through coding will determine the facility and accuracy with which the operator can manipulate the information presented on the display.

Unfortunately, there are very few stereotypic associations between coding dimensions and specific items of information, and any practical suggestions on this topic will be sketchy at best. Apart from purely pictorial representations, the following are the symbol meanings most frequently cited in the limited research literature available.

1. Crossed lines generally indicate a fixed or reference point.

2. Location is at the geometric center of a symbol or at a dot.

3. An arrow points in the direction of travel.

4. Size or number indicates magnitude.

5. A flickering symbol indicates emergency.

6. Red stands for danger, warning, or emergency; yellow for caution; and green for satisfactory, operable or "go".

Table 18 on the following page is a summary of the significant characteristics of the coding dimensions appropriate for E/O displays.

TABLE 18 - SUMMARY OF CODING DIMENSIONS

DIMENSION	NUMBER OF STEPS	EVALUATION	COMBINES WITH	REMARKS
Size	4 - 5	Fair	Shape, Color, Brightness	Requires considerable display space. Limited usefulness. Best when used in combination codes.
Shape	15	Excellent	Size, Color, Motion, Flash, Brightness	Certain shapes easily recognized. Requires good contrast and resolution. Combines well with other codes.
Alphanumerics	Unlimited	Excellent	Color, Brightness	Requires good contrast and resolution. Easily learned.
Color	11	Excellent	Size, Shape, Alphanumerics, Motion, Flash	Recognizable colors on CRTs limited to 4 - 7. Combines well with other codes.
Motion	1 - 2	Poor	Shape, Color, Brightness	Hard to discriminate. Not recommended except for getting attention or to supplement other codes.
Flash	1 - 3	Poor	Shape, Color	Distracting and fatiguing. Not recommended except for getting attention.
Brightness	7	Fair - Good	Size, Shape, Alphanumerics, Motion	Requires good contrast. Best when combines with other codes, as in shades of gray.

REFERENCE SYSTEM AND DISPLAY DYNAMICS

The Framework

Flying is essentially an activity in which the pilot's task is to determine what situation exists and to take action to make the flight profile conform to some future, desired situation. Carel (1965) sums up the pilot's task in four questions.

> Where am I with respect to my destination and desired route?
>
> Where is and what should be my velocity vector?
>
> What is and should be my attitude, thrust, and configuration?
>
> What should I do with the controls?

These questions define, according to Carel, a hierarchy of goals and tasks for the pilot. The answer to the first question implies certain more specific questions to be asked and answered at the next lower level. These, in turn, lead to still more specific questions until finally the pilot reaches the lowest level, at which he takes some particular control action. This will produce a change in attitude, thrust, or configuration, which will affect the velocity vector and -- ultimately -- the flight path with respect to the destination. The pilot's role, therefore, consists of an iterative descent and ascent of this hierarchy, meeting goals at one level by determining sub-goals and tasks at subordinate levels until he closes the loop with a specific control action and reascends the ladder of goals and tasks.

The purpose of the display is to support this activity by providing the pilot with information about the present and future of the aircraft. The information content of the display is important; so, too, the coding techniques used to translate the information into a readily perceptible and recognizable form. Of equal importance, however, is the way in which the information is structured. Structure not only serves to define and describe the relationships among the parts of the situation; it also serves to define the whole and determine what is relevant, *i.e.*, what is and is not part of the situation. However, for structure to have some influence on information processing it is not enough that it simply be present; it must be recognized as such by the human information processor.

The spatial ordering or structuring of a display is perhaps the most basic of design questions since it is within this framework that the entire display must be organized. In structuring the display the two basic parts of the pilot's task must be kept in mind. First, the pilot must determine his position, attitude, and velocity vector with respect to the real world. This suggests that the display must in some way reproduce the familiar structure of the external world. However, the pilot must also take action

based on his assessment of the situation to make the flight path conform to his wishes. This implies that the structure of the display must be related to his control tasks. That is, the display provides the pilot with an index of actual performance and an index of desired performance. At least one of these indices will move as a result of manipulating the controls. Ideally, the reference system of the display should be related to cockpit coordinates and the movement of display elements should be consonant with specific control actions.

The basic aircraft situation is three-dimensional (X-Y-Z); but the display being planar, permits only two coordinate axes to be used as a reference system. The customary solution is to present two separate views of the flight domain which are related by having one common dimension. The vertical situation display is a projection of the flight situation in azimuth and elevation (Y-Z) on a vertical plane ahead of the aircraft. This provides a reference system for pitch, roll, heading, angle of attack, and steering, all of which may be expressed either as translations or rotations with respect to display coordinates. The horizontal situation display is a projection of the flight situation downward upon a horizontal plane beneath the aircraft. This is a reference system in X-Y in which geographic position, heading, course, and track can be presented by appropriate translations and rotations. It is also possible to show the aircraft situation in an X-Z coordinate system, sometimes called an E-scan or a range-elevation display. E-scan displays have found some application in terrain following presentations, but their use is limited because such displays suffer from the disadvantage of inconsistency with aircraft control system coordinates. The VSD and HSD, by contrast, are compatible both with the real world and control system coordinates, and for this reason they are the most widely used.

Integration

The central problem of display design is to find ways of integrating the parameters of flight into the horizontal and vertical coordinate systems. As a first step it is necessary to find a rationale for assigning certain classes of information to each coordinate system or view of the flight domain. Carel (1965) and Roscoe (1967) suggest a solution to the problem of allocation can be found by referring to the hierarchical nature of pilot tasks. That is, information about position, route, and destination is hierarchically related and should be presented in a common reference system. The HSD is the appropriate site for such information since it is in X-Y that the position and route of the aircraft are described. Information relating to velocity vector and attitude fall within another level of the hierarchy and are best portrayed in the coordinates of a VSD. This scheme has the additional advantage of allocating short-term aircraft response characteristics to one display, the VSD, and more slowly changing aspects of the situation to another, the HSD. The arguments of Carel and Roscoe on this matter are convincing, and this position seems to be one

that is generally held by display designers. At least, the practice in contemporary display design seems to reflect an allocation scheme of this sort.

Further questions of what can be integrated into the VSD and HSD framework and how it is to be done do not yield so readily to solution. In part, the difficulty stems from a disagreement about just what constitutes integration. Sampson and Wade (1961) say that the concept of integration implies a variety of procedures by means of which the operator is relieved of the need to integrate information because the equipment does it for him. Displays may be said to be integrated when the information presented to the operator has been corrected, transformed, filtered, referenced, made more natural or direct, or has in some other way been processed so that the operator does not have to perform these operations for himself. Sampson and Wade further distinguish between on-the-panel integration and behind-the-panel integration. The former refers to structuring, referencing, or organizing data while the latter is primarily concerned with automatic data processing and transformation. Only on-the-panel integration is of concern for the moment.

One definition of on-the-panel integration is that it consists of combining several indications in a single instrument or display. Considerable research has been devoted over the years to developing such combined aircraft instruments. One such is the horizontal situation indicator (HSI) now in common use. It combines compass heading, course, omni or Tacan selection, ADF, and approach path indications. Another so-called integrated instrument is the attitude director indicator (ADI) which combines a gyro-stabilized attitude sphere, compass heading, flight director and ILS cross pointers. Integration, in this sense, implies physical combination of two or more indicators in some common or compatible reference system. The best example of this type of integration is the standard Air Force T arrangement of flight instruments, which consists of a centrally located attitude and flight director instrument flanked by airspeed and altitude tapes. Directly below the ADI-Flight Director is a Horizontal Situation Indicator (HSI). Attitude, airspeed, and altitude are read with reference to a single horizontal line extending across the displays. A single vertical line extending through the ADI-Flight Director and HSI completes the T and provides a reference for information such as heading, steering, and course.

A more stringent definition of integration is that all information about the flight situation must be presented within a common reference system which is compatible with earth coordinates, aircraft coordinates, or -- preferably -- both. This definition leads to a predominantly pictorial display on which the visual cues important to aircraft control are synthetically reproduced. Purely symbolic indications are kept to a minimum and are used only when "natural" cues are inadequate or impossible to present pictorially. The proponents of this type of integration maintain that it yields a display which is more easily learned and interpreted because it

corresponds directly to the pilot's visual experience with the external world. Further, it allows more than one element of aircraft performance to be seen at one time and makes relationships between these elements easier to perceive. Also, because all elements are contained within a common reference, it is possible to comprehend the situation as a whole and to see how the parts relate to the whole.

Of the two definitions of integration we tend to favor the latter. The crux of the pilot's information processing task is in determining the relationships which exist between the elements of the flight situation. It seems reasonable to conclude that the best way to help the pilot reach solutions about real world relationships is to create a display which preserves these relationships. Such a display has the twin virtues of naturalness and of directness of association between what is represented and its representation. A display structured and integrated in terms of real world and aircraft coordinates will entail the minimum number of transformations for the pilot in converting information into action.

It is apparent, however, that not all the parameters of flight can be integrated into a common reference system. Airspeed, altitude, and vertical velocity, for example, cannot conveniently be expressed in VSD or HSD dimensions even though they are related to the X, Y, and Z axes of the real world situation. Further, there are non-spatial quantities such as time to go, friendly or hostile, and fuel quantity which cannot be fitted into any basic reference system which also contains pitch, roll, heading, and the like. Thus, it is evident that total integration of information, however desirable, is not truly possible and that some items of information will have to be displayed separately or encoded symbolically. That is, they may be presented in proximity to the display or even on the display, but they cannot be an integrated part of the display. Whether and how to include this information is a long standing problem in display design. We will not further interupt the discussion of the display reference system by going deeper into these questions here. Some of the techniques commonly employed for displaying this kind of information will be taken up at the end of this chapter.

Related to the concept of integration as we view it is the notion of realism. It has been stated that one of the advantages of integration is that it provides for presentation of information in a natural way which is consistent with the real world. This is to say that the display must correspond to reality as the pilot perceives it. A display whose content is encoded graphically and structured in real world coordinates will be most readily interpreted because it is veridical. Wulfeck *et al.* (1958) suggest that it would probably be more economical and efficient to present data in the language and number symbols which the pilot customarily uses in his thought processes rather than in a picture. On the other hand, they continue, symbols are not the real thing and learning is required to use them properly. The possibility of incorrect interpretation of symbols always exists since they call for a number of cognitive steps or transformations.

Pictorial displays appear to require less learning, to be more readily interpretable, and to give rise to fewer errors.

The element of realism is predominant in the contact analog display, which presents a stylized pictorial recreation of the real world scene as it would be in VFR flight. The basic notion of the contact analog is that the display should serve as a surrogate or pictorial analog of the external visual world. Carel (1965) holds a slightly different view. He maintains that pictorial realism is not nearly so important as kinematic realism. That is, the display need present only a skeletal representation of the real world, just sufficient to suggest its predominant physical features. It is of prime importance, however, that the display be fully realistic in its motion relationships and that it faithfully represent the dynamic aspects of flight. A third, and somewhat novel, view is that of Fogel (1963). He points out that vestibular and kinesthetic cues play an equally important role to that of vision in maintaining orientation in flight. He contends that an attitude and flight control display should be realistic both to the visual sense and to the pilot's internal sense of orientation. To this end, he proposes a display design which is a kinesthetic analog *(kinalog)* of the human operator. With this display a movable element representing the aircraft rotates in relation to a fixed horizon as the aircraft banked. The symbol remains rotated as long as the kinesthetic and vestibular cues of being tilted predominate. However, as the body adapts to this new orientation, the aircraft symbol slowly rights itself. The horizon line, meanwhile, begins to rotate in the opposite direction in order to preserve a correct visual indication of the bank angle of the aircraft. Thus, the display is initially an outside-in display but, as time passes, gradually proceeds toward an inside-out display in an exponential manner. The position along this inside-out, outside-in continuum depends both on the passage of time and the magnitude of the g force sensed by the pilot.

Despite differing views as to what parts of experience to draw upon, these investigators are unanimous in their emphasis on realism. Fidelity to the real world, however one chooses to define it, is an essential feature of integrated flight displays. These investigators are also correct in their emphasis on the dynamic aspects of the flight situation. The structure of a display involves more than just consideration of how elements are spatially ordered. It is equally important to consider how the elements of the display move in response to changes in the aircraft situation.

Display Dynamics

As viewed from the cockpit, the elements of the visual world move with six degrees of freedom. They may translate along one or more of the X, Y, and Z coordinates; and they may rotate about any of these three axes. The question is how to represent these motions within the display coordinate

system. The usual way of phrasing this question is in terms of inside-out or outside-in. An *inside-out*, or earth referenced, display presents a view analogous to what the pilot would have looking out of the aircraft. The display shows not aircraft movements but changes in the position of earth elements in response to aircraft movements. Thus, the aircraft symbol on a VSD remains fixed while the horizon line translates and rotates as a function of pitch and roll. With an *outside-in*, or aircraft stabilized, display the horizon line and other earth elements remain fixed, and the aircraft symbol rotates and translates to indicate changes in attitude. The presentation is analogous to the view one would have from outside the aircraft, watching it maneuver against a fixed ground plane. For horizontal situation displays the terms moving or fixed map are also used to denote this difference. A *moving map* display is an inside-out display in that the aircraft symbol remain fixed while the map moves beneath it just as the earth appears to do when looking down from the aircraft. With a *fixed map* display (outside-in) the aircraft symbol moves across the map as the aircraft would do if one were looking at it from the outside. The basic difference between the two types of display is what the moving part represents. With an inside-out display the aircraft is fixed, and control actions produce a reciprocal movement of the moving part which represents some element of the real world. On an outside-in display the moving part stands for the aircraft, which maneuvers in direct response to control movement.

The term *fly-to* is also used to designate an inside-out display and *fly-from* to designate an outside-in display. Fly-to and fly-from, however usually have a more general meaning. Fly-to is any form of command presentation in which the proper response is to move the vehicle in the direction of the movable element. An inside-out attitude display is fly-to in the sense that deviation from level flight is corrected by flying toward the moving element or horizon line. With a fly-from display the response is just the opposite. Control action must be taken to displace the movable element from its present location back to a fixed reference location. An outside-in display is fly-from in that the movable aircraft symbol is flown back to a fixed horizon to neutralize a deviation from level flight. Another way of looking at the difference between fly-to and fly-from is in terms of status and command. On a fly-from display the movable element represents the status of the aircraft with respect to some variable. With a fly-to display the movable element indicates the command value for the variable.

The number and interchangability of terms to describe display motion sometimes leads to confusion. In particular, some writers have been a little too free about the exchange of fly-to for inside-out and fly-from for outside-in. The usual practice is to use inside-out and outside-in to designate the basic forms of attitude display. Fly-to and fly-from should not be used for this purpose. Rather, they should be reserved as designations for methods of presenting command information. While the terms

moving map and fixed map are certainly not objectionable, we prefer not to use them since they are merely synonyms for inside-out and outside-in in the special case of navigational displays.

In this connection, it may also be worthwhile to touch on the distinction between *compensatory tracking* and *pursuit tracking*. These terms also refer to methods of presenting command information. A command display is one on which the operator is presented with an index of desired performance and an index of actual performance. His task is to manipulate a control to eliminate any discrepancy which may exist between the two indices. This task is called *tracking*. In *compensatory* tracking only one of the indices of performance moves; the other is fixed. If the index of desired performance moves, the command presentation is fly-to. If the index of actual performance moves, it is fly-from. With either, the operator is presented only with a statement of the combined error between the performance of his own vehicle and the tracked variable. In some circumstances, however, both the vehicle and the tracked variable are capable of independent variation. Such is the case when an aircraft is pursuing a moving target. That is, the positions of the aircraft and the target are variable not only with respect to each other, but also with respect to the earth. Here it may be desirable to provide the operator with a display which shows the performance of each element independently. Such a display is called a *pursuit* tracking display. In this case both the index of actual performance and the index of desired performance move independently against a fixed reference. The operator has not only a statement of the error between his performance and the command variable, but also an indication of how each varies with respect to a common reference. Thus, he is in a position to know how much of the total error is contributed by each element.

Dynamics is one of the most intensively investigated areas in display design. The literature on this topic is too voluminous to present in any detail, so we shall cite only examples to show the general lines of investigation and the trend of the findings. There is no single reference document to which we can refer the reader interested in going into the subject in depth. Standard human engineering references such as Morgan *et al.* (1963) and McCormick (1964) contain informative discussions and provide good general bibliographies. Baker and Grether (1954), Williams *et al.* (1956), Wulfeck *et al.* (1958), Fogel (1963), and Carel (1965) all deal extensively with the questions of dynamics as it applies to airborne displays, and together they contain citations of most of the specialized studies conducted during the period 1945-1965. There are two other investigators, R. B. Loucks and H. P. Birmingham, who have conducted numerous studies on the subject. Unfortunately, the findings of neither have been compiled in a single document, but a literature search under these names will turn up several pertinent references.

The question of inside-out *vs.* outside-in is one of the most thoroughly investigated topics in display design. Nonetheless it still remains a hotly controversial issue. Loucks (1945) compared four different types

of attitude indicators with the standard Air Force inside-out instrument. He found that the best performance was obtained with an outside-in indicator on which the reference horizon line remained fixed and the aircraft symbol moved in such a manner that it rotated clockwise when the aircraft rolled right and counterclockwise when the aircraft rolled left. Not only was such a display more easily interpreted, it was the one consistently preferred by the subjects participating in the experiment. Browne (1945) obtained almost identical results in simulator studies with naive subjects. Browne felt that it was more appropriate to use inexperienced subjects rather than pilots to test the interpretability of attitude displays since the previous experience of pilots with conventional inside-out instruments might tend to distort the results. However, Fitts and Jones (1947) found in flight trials that experienced pilots also performed better, *i.e.*, responded more quickly and experienced fewer control reversals, with an outside-in form of presentation. A similar conclusion was reached by Gardner and Lacey (1954) in simulator studies with experienced pilots. Duerfeldt (1956) conducted flight trials of an outside-in "moving airplane" attitude display using 14 Navy pilots. He concluded that the display was suitable for all-weather flight and compatible with a variety of aircraft maneuvers. He did not feel that extensive retraining would be necessary for the experienced pilot to transition from the conventional to an outside-in attitude display. A study by Bauerschmidt and Roscoe (1960) showed significantly greater accuracy of performance with an outside-in steering and attitude display in comparison to a conventional inside-out display. Errors were five times greater with the inside-out display, and there were 18 times as many control reversals. The results were all the more significant in view of the fact that the subjects were pilots whose entire previous experience had been with the conventional moving-horizon type of presentation.

Experimental evidence as to the superiority of the outside-in concept is not confined to attitude displays. Payne (1952) investigated two pictorial navigation displays, one representing the aircraft movement principle and the other the map movement principle. The aircraft movement (outside-in) display was found to be superior. Specifically, the subjects were able to initiate a solution more rapidly, made fewer first turns in the wrong direction, had fewer control reversals, manipulated the control stick less, and attended to a secondary task more efficiently with the moving aircraft display. It was suggested that the fixed map should present a portion of the path to be flown and that the entire configuration should be manually rotatable to a "heading-up" orientation. Wulfeck *et al.* (1958) cite an undated report by Williams which supports the conclusion that an outside-in form of presentation is superior to an inside-out for navigation displays.

As might be expected, the preponderance of experimental evidence on the related topic of fly-to *vs.* fly-from favors the fly-from concept. Loucks (1949b) demonstrated in a simulator experiment that inexperienced pilots were better able to control a localizer-glide-slope approach when the

crossed pointers of the instrument represented the position of the aircraft than when they represented the command glideslope and glidepath. Confirmation of this can be found in Gardner (1950) and Baker and Grether (1954). Fitts *et al.* (1949) in a study of pilot eye movements discovered that pilots tended to refer more often and to dwell longer on displays where the moving element represented the outside world. They concluded that displays with a moving index and fixed scale (fly-from) were easier to read because unique positions on the displays had unique meanings. A study by Christiensen (1955), cited in Roscoe (1967), similarly concluded that fly-from presentations (in this case moving pointer, fixed scale indicators) were to be preferred. A study by Loucks (1949a) showed that the fly-from principle was also superior for circular displays of azimuth and heading. Other later experimental evidence indicates that Louck's conclusion can be applied to map displays in general.

As one-sided as the experimental evidence is, one must be cautious about concluding that the matter is settled. The simple fact is that all present conventional attitude and steering instruments and all contemporary vertical situation displays are inside-out, fly-to indicators. It would appear that there has either been a complete breakdown in the dialogue between researchers and display designers and/or military service users or that factors other than ease of interpretation and accuracy of control must be taken into account. To attribute the disparity between theory and practice to lack of persuasiveness on one side or to obstinacy on the other is to take too simple a view of the matter. The difference of opinion is legitimate, and there is a strong case to be made on both sides. The inside-out/outside-in problem is one of the paramount issues facing a standards committee.

To sum up the case for having the aircraft symbol move we shall paraphrase Roscoe (1967). When the pilot moves a control, he expects the corresponding display element to move in the same direction so that up means up, down means down, right means right, or clockwise, and left means left or counterclockwise. Movement relationships of this sort are "natural" in that there is consonance between the coordinates of the display and the aircraft control system. Even more basically, the pilot knows that he is a vehicle moving with respect to a stationary world. Thus, when he moves a control, he knows he is controlling his vehicle, not the outside world relative to his vehicle, and therefore he expects the symbols representing his vehicle to move. Note that the argument is cast not in terms of sensation and perception but in terms of cognition, *i.e.*, what the pilot *knows* to be true. However, the justification for an outside-in reference system can also be based on perceptual grounds. In an earlier report (Roscoe, 1954), the following argument is advanced.

> *"A pilot when flying contact perceives his airplane as moving against a fixed, stable outside world. <u>If the world moves, he has vertigo</u>. Apparently this same natural relationship should be preserved*

in the cockpit. Clearly the movement of a display index is its most compelling stimulus property, and therefore it should represent the movement of the airplane against a fixed reference representing the outside world."

One of the counterarguments to this view is based on the assertion that pilots prefer, perhaps because of their prior instrument experience, an inside-out indicator. Our own discussions with pilots tend to bear this out. A recent study (Dehan *et al.*, 1965) undertook to sample pilot opinion on this and other topics of display design. While there was a slight preference found for inside-out displays and fly-to commands, the difference was not judged to be statistically significant. On the other hand, a clear-cut and significant preference was shown for moving scale, fixed pointer presentations of airspeed and altitude, which is to say fly-to indicators. The sample sizes were, however, small (25 and 33), and it is doubtful that the results can be generalized to the pilot population as a whole.

Wulfeck *et al.* (1958) point out that the outside-in principle has not been firmly established as superior for all flight instruments despite experimental evidence that this type of display is easier to learn, use, and interpret. They suggest that one reason for the preference of the experienced pilot for inside-out, earth-reference displays is that he is able to associate, from visual, vestibular, and gravitational cues, the fixed position of the indicator with his aircraft. With the aircraft-reference display he cannot perform this natural association. They conclude:

> *"This may be the real reason pilots dislike the airplane-reference type and not the fact that they were not trained with it. The presence of what has been regarded as experimental evidence that the airplane-reference type is better may be due to the fact that these vestibular and gravitational cues are negligible or absent in experimentation using simulators."*

In fairness, we should add that not all evidence of the superiority of outside-in displays comes from simulator studies. Of those previously cited, Fitts and Jones (1947) and Duerfeldt (1956) were conducted by flight trials. Roscoe (1967) mentions flight experiments performed at the University of Illinois, the Hughes Aircraft Company, and Miramar Naval Air Station. He also states that airline experience with outside-in displays supports the superiority of this type of attitude indicator but does not elaborate.

Nevertheless, it is true that the experience of the vast majority of pilots has been with inside-out displays. The services have shown a natural and prudent reluctance to incorporate experimental findings in the design of

new outside-in displays because of the retraining required and the fear that older, experienced pilots would have difficulty in adapting. Several studies, *e.g.*, Fitts and Jones (1947), Gardner and Lacey (1954), Roscoe (1954), and Bauerschmidt and Roscoe (1960), have demonstrated that the process of transition is not as difficult for experienced pilots as one might suppose. These studies, however, did not involve hazardous or high stress situations, and there remains a legitimate fear that in a pinch the pilot with a predominance of experience with inside-out and fly-to instruments might revert to his earlier habits. One must admit that it is a bit extreme to risk a whole generation of experienced pilots to prove a principle.

Even if such a risk were acceptable, there remains an even greater source of danger. Conventional aircraft instruments have been standardized by MIL-I-27193 on the inside-out principle. For reasons of reliability it is customary to include in the cockpit conventional electro-mechanical devices as supplements or back-ups to E/O displays. If E/O displays were outside-in and standard instruments were inside-out, the situation would be impossible. A pilot whose primary E/O display had failed would have to fall back on conventional instruments as a standby. Thus, a pilot in trouble would be led into even deeper trouble because he would be forced to adjust to a new reference system as well as to an unfamiliar source of command and attitude information. The hazard of such a situation is clearly intolerable. All command and attitude displays in the cockpit which are used either concurrently or alternatively for the same purpose will have to be either inside-out or outside-in, but absolutely not a mixture of the two.

The most critical, although perhaps not a necessary, test of the outside-in concept is one that has not yet been undertaken experimentally. All of the studies of outside-in displays have made use of direct view displays where the pilot's command and attitude reference was within the cockpit. We know of no case where an outside-in head-up display has been tested. With a head-up display the pilot would be confronted with two diametrically opposed views of the world. The real world horizon would rotate counterclockwise in a right roll, but the display horizon would remain fixed while the moving symbol representing the aircraft would rotate clockwise. Similarly, the real world horizon would move in the opposite direction from the movable aircraft symbol of the display in a pitch maneuver. If it is undesirable to have a mixture of reference systems on two separate indicators within the cockpit, how much worse would it be to have two conflicting frames of reference on one display?

There is some experimental evidence that a certain amount of misregistration or even conflict between the symbols and the real world can be tolerated on a head-up display. Naish (1961, 1962, 1964, 1965) indicates that the scaling between head-up display symbols and the real world need not be one-to-one. Compression factors of up to 1:10 are acceptable according

to Naish. In the other direction, Roscoe *et al.* (1952) and Campbell *et al.* (1955) found that magnification factors of 1.2:1 or 1.3:1 actually led to better performance. It has also been found by Naish that display elements such as the horizon line or runway symbol need not be congruent or coincident with their real world counterparts. Lambert (1964) even reports an incident where a purposely erroneous flight path command on a terrain following head-up display was promptly recognized as such and disregarded. The spurious command called for a pitch down maneuver, but the real world obstacle lay above the flight path, which meant that a pull-up was required. The incident is particularly impressive because the pilot, although qualified on instruments, was a novice in flying a head-up display. In all these cases, however, there was no conflict between the pilot's basic visual frame of reference and that of the display, in that movement was in the same direction if not of the same magnitude.

We cannot predict the consequences of superimposing an outside-in display on an inside-out world, but we do believe it would be worthwhile to investigate a display of this sort. Some display designs today call for both a direct view and a head-up display. More will probably do so as time goes on. If it turns out that the head-up display must be inside-out to be compatible with the real world, then it is likely that the direct view display should be inside-out also. If on the other hand it turns out that an outside-in head-up display is preferable, or even just acceptable, this will be a very strong argument for re-examination of the issue of inside-out *vs.* outside-in for all cockpit indicators, E/O displays and conventional instruments alike.

The issue of inside-out or outside-in is not so sharply drawn in the case of horizontal situation displays. The purpose of these displays is to maintain orientation is space with respect to geographic and navigation references or with respect to the tactical situation. The HSD tends to be used less frequently by the pilot, who scans it intermittently rather than flying it continuously as he does a VSD. In part this is attributable to the rather slowly changing nature of HSD information and to the fact that pilot actions are usually more in the nature of decisions than immediate control movements. Baker and Grether (1954) point out that in actual practice it is often difficult to judge whether the HSD is primarily a flight or orientation instrument. Thus, the distinction between earth- or aircraft-reference does not seem as important, and either principle may be satisfactory for the HSD.

The thinking of designers and experimenters on HSDs seems to have changed over the years. In earlier reference documents there is a preference for the outside-in principle, but more recent articles and navigation display designs seem to have swung over to the inside-out principle. All of the HSDs examined in Chapter III and most of the displays described in the proceedings of the 1966 JANAIR symposium on aeronautical charts and map displays (JANAIR, 1966) are inside-out, moving map displays. Typical of

this reversal of opinion is the view expressed by Roscoe at the JANAIR symposium. (See JANAIR, 1966, or a later version published in the September/October 1967 issue of *Information Display*.)

> *"Another classic question is: what should move, the aircraft symbol or the map? Obviously there are advantages and disadvantages to both schemes. Ten years ago I was positive the aircraft should move against a fixed map as it does on practically all early map displays built during the 1950s. Now I am almost equally convinced that, on balance, having the chart move provides more really important advantages. The biggest single advantage is that it reduces the frequency with which charts must be changed by the crew. Even if charts were changed automatically, frequent chart changing is objectionable, and operating near the edge of a fixed chart restricts the field of view about the aircraft."*

Inside-out navigation displays, on which the map moves, suffer from the disadvantage of having alphanumeric symbols and map legends disoriented with respect to the display framework. That is, if the path of the aircraft is anything but northerly, the letters and numerals will appear upside down or tilted with respect to the track. Fixed map displays do not have this disadvantage so long as the map is kept in a north-up orientation. However, on fixed map displays the motion of the aircraft symbol often does not coincide in cockpit coordinates with the path of the aircraft, which may lead to control reversals. For this reason, fixed map displays usually have a control which allows the moving symbol to be oriented to a vertical position, thus introducing the same disorientation of alphanumerics as moving map displays. The solution is to make the map display, either of the inside-out or the outside-in variety, rotatable to a heading-up or north-up orientation. Since the horizontal situation evolves rather slowly and usually does not call for quick action, the need to reorient the display from time to time is not felt to be a nuisance or a burden.

Some Display Solutions

The embodiment of the principles of naturalness and fidelity to the visual world is the contact analog display. The essentials of the contact analog concept are that the display should contain a realistic representation of the elements of the real world to which the operator would respond if he could see them directly and that these display elements should respond to the same laws which govern their real world counterparts. The JANAIR contact analog display and simulator now at USNMC/Point Mugu is the purest example of this display concept. This display consists of a ground plane, sky plane, flight path, ground patch (runway, checkpoint, or target) and

stylized ground objects or obstacles. All display elements respond with six degrees of freedom, except the sky plane which responds only in rotation (three degrees of freedom). Sky and ground texture elements are also variable in shape, size, density, and color. This display is an experimental device only and is not intended for airborne use. The best example of an airborne contact analog display is the AAAIS, which was analyzed in Chapter III. While not as rich in textural cues as the JANAIR simulator nor as pictorially realistic, the AAAIS display is, nonetheless, a pure contact analog. These displays contain no scales or numerical indications and symbolic (as opposed to pictorial) elements are rarely used. The purpose of both these displays is to investigate how fully and accurately flight can be controlled by purely pictorial means.

The evaluation programs for both these displays are still in progress, so it would be premature to speak of results. However, there has been sufficient experience with the contact analog as a display concept for certain inadequacies and problems to have emerged. The early contact analog displays suffered from an inadequate presentation of airspeed, which was judged from the speed of movement of textural elements. Estimates tended to be inaccurate and high. To overcome this the tarstrip or dashed line symbology was devised. Speed, in relation to a command value, is shown by the motion of a series of elements along the flight path symbol. If the elements move up the display (or, because of perspective, away from the observer), actual airspeed is less than command airspeed. Movement of the elements downward or toward the observer indicates that actual airspeed is greater than command airspeed. The objective is to control speed so that the elements remain stationary. If the sensitivity is properly selected, this technique of display should permit reasonably accuracт control of airspeed. Similar techniques were devised for altitude control One involves changing the size and pattern of ground texture elements to show altitude either absolutely or in relation to a command value. Another, used on the AAAIS display, employs variation of the angle at the apex of the flight path symbol. This was described more fully in Chapter III in the analysis of the AAAIS display.

A second shortcoming of the contact analog display is that it presents only visual cues about the real world. The contention is that by extracting the meaningful visual cues from the external environment and recreating them on the display, adequate control of flight can be maintained. The flaw in this argument is that, while the relevant cues may be embedded in the real world scene, the human cannot extract them with sufficient clarity and precision to meet the demands of flight. The human capacity to determine velocity and acceleration is notoriously weak, and yet these are highly important to flight. Further, expert pilots have difficulty in estimating altitude to within 10% in contact flight. The same inaccuracy might be expected to obtain on a display which presents visual cues like those of the real world. Finally, of course, there is some information

which does not occur in the visual scene at all but must be derived from other items. Examples of these are pressure altitude, time to go, or fuel range. The most resounding refutation of the contact analog argument is that pilots habitually use instruments even in perfect VFR weather over familiar terrain.

All of this is not to say that the contact analog concept is of no value. It is simply that the pictorial analog is not sufficient, in and of itself, to meet all the requirements of flight control. The pilot's task involves number and quantity. He must have a display which tells him more than he can extract for himself from the visual world and which unburdens him of some of the task of information derivation and integration. In this regard, the findings of an experiment by Emery and Koch (1965) are significant. They measured the ability of a group of helicopter pilots to perform rotary wing maneuvers with three different versions of the JANAIR contact analog display augmented with numeric information. Moving tape scales, moving pointer scales, and digital readouts were each presented with the basic grid plane and compared with each other and with the grid plane alone. The numeric information displayed included indices of altitude, airspeed, and heading. The display was tested for a relatively stable cruise task and a variable terrain following task. Measurements were made of altitude control, airspeed control, heading control; and appropriate collective control inputs were recorded. The results indicated that numeric information significantly enhanced performance when presented in conjunction with the contact analog and that moving tape and moving pointer indicators each produced significantly better scores than digital readouts. These results were consistent in both of the flight tasks tested.

From the survey of displays in Chapter III it is apparent that pictorialism is firmly established as a design feature. Most of these displays are not contact analogs in the strict sense of the term, but all are pictorial to some extent, and all do recreate with varying degrees of literalness a real world scene. However, it is also clear that most designers have concluded that pictorial displays require some supplementary symbolic indications of quantitative information since the cues from visual flight alone are deficient in this respect. Thus, we have a variety of designs which present a stylized and skeletal view of the world augmented with scales and other such means of presenting quantitative data. Some of these displays, notably the Norden IEVD, the IHAS display, and the A-7 D/E head-up display, have made extensive use of scales. These displays seem to have departed the farthest from the contact analog concept and give the impression that the designers chose as their model not the external visual world but the pilot's conventional instrument array. This is most certainly the case with the Mark II avionics displays of the F-111A aircraft, where the basic design concept was to create on the E/O display an aggregate of the standard panel instruments. Thus, we have in current display design a continuum with the purely pictorial display, represented by the contact analog, at one end. At the other is a purely symbolic display, of which the Mark II display is

the best example, although it still retains many pictorial qualities. Most displays fall somewhere nearer the middle of the continuum, and it appears that the goal being sought is a judicious balance between symbolic indications to attain the required precision of flight control and pictorial realism to preserve an overview of the situation and retain spatial orientation.

The principle of inside-out presentation is solidly established in contemporary designs both for VSDs and HSDs. In part this can be attributed to the prevalence of the contact analog concept which seems to have served as the point of departure for most of the direct view VSDs. The contact analog requires, of necessity, an inside-out presentation. For skeletal displays, such as head-up displays, inside-out is also standard -- probably for the very good reason that head-up display symbols are often intended to overlay their real world counterparts and therefore must move with them. However, even for those head-up displays which are not scaled one-to-one with the real world, the directional sense of symbol movement in relation to the real world has been preserved without exception. Another, and we suspect the dominant, reason for the universal acceptance of the inside-out principle in contemporary display design is that the displays are intended for use in cockpits which also contain conventional electro-mechanical indicators. This, plus the weight of traditional practice, seems to have precluded any other solution of E/O displays.

Current display designs also reflect a third area of agreement. Steering is always presented as a fly-to command; and, with the possible exception of the A-7D/E display, it is always a compensatory tracking task. This agreement does not extend, however, to other forms of command presentation, particularly those indicated on scales. There are both moving scale (fly-to) and fixed scale (fly-from) presentations of airspeed, altitude, vertical velocity, and angle of attack. In some cases there is even a mixture of the two types of presentation on the same display. We can offer no explanation for this lack of consistency except that the determination of how the scale and pointer should move was probably based on other considerations such as the range of values to be displayed, the amount of space available, and the ease of mechanization.

There are two novel display design concepts which offer a compromise on the inside-out *vs.* outside-in issue. One of these is the *kinalog* display proposed by Fogel (1963). This display concept was discussed earlier in the context of integration and display realism. The basic feature of the kinalog is that it responds as both a visual and a kinesthetic analog. Over time it progresses from an outside-in to an inside-out display but always preserves a true indication of roll and pitch in the relative positions of the aircraft and horizon symbols. The second design concept, called *frequency separation,* is really only a more general version of the kinalog. It has been proposed by several people, most recently Roscoe (1967). In frequency separation the central idea is that the elements of a display which respond immediately to control inputs should move in the

expected direction, *i.e.*, in the same direction as the control. For more slowly responding elements the direction of movement is far less critical. This leads to the notion that high frequency variations be displayed in a cockpit frame of reference (outside-in) while lower frequency variations be presented in earth reference (inside-out). Neither of these design concepts has been translated into hardware and evaluated experimentally. They do offer interesting possibilities and merit investigation as a resolution of the inside-out/outside-in dilemma.

Summary

The principles of display structure and dynamics are basic to any philosophy of information display, and must be incorporated in any future standard governing the design of E/O displays. The purpose of this section has been to examine the more important aspects of the problem and to review the experimental evidence which can be brought to bear in reaching a solution. All in all, there seems to be wide understanding of what the problems are and general agreement on the elements, if not the details, of the solution. There are still controversial subjects, the most notable being the issue of an earth or aircraft reference system for display motion, but even here it seems possible to reach some sort of agreement or working arrangement.

It is generally agreed that flight displays must be spatially structured and that the coordinates of the display system must relate to both aircraft and earth coordinates. The most appropriate display for control of short-term, high-frequency aircraft response characteristics is the vertical situation display. The horizontal axis of the VSD relates to changes in azimuth in earth coordinates and to lateral stick motion and left-right rudder pedal action in fixed-wing aircraft control coordinates. The vertical axis of the display relates elevation angle or pitch in terms of the earth and to fore-aft stick motion in the aircraft. For helicopters the coordinates of the VSD similarly correspond to the action of the cyclic and collective controls and the foot pedals, although the relationships are a bit more complex. The horizontal situation display is appropriate for the presentation of more slowly changing aspects of the aircraft situation. The horizontal and vertical axes of the display relate to latitude and longitude coordinates in earth terms and to aircraft controls which affect the direction and speed (velocity vector) of the aircraft in a horizontal plane. For HSDs it is desirable that they be designed to permit the operator to select a heading-up or north-up orientation.

It is apparent that not all the parameters of flight can be integrated into the VSD and HSD reference systems. In the case of the VSD airspeed, altitude, and vertical velocity are difficult to express in the display coordinate system. It is similarly difficult to express altitude and vertical velocity on the HSD, although the latter is probably not an appropriate item for inclusion in the horizontal situation. There are other

non-spatial parameters, such as time functions and qualitative distinctions, which cannot be stated in dimensions compatible with the VSD or HSD coordinate systems. For all these items it is necessary to use symbolic coding techniques and non-spatial analogs. While it is possible to present such parameters within these boundaries of the display, care must be taken in their placement and arrangement so as not to interfere with the interpretation of the basic spatial analog. It is also important that the movement of these symbols, especially scales and pointers, be compatible with the general movement relationships of the display in so far as possible.

The most persistent controversy in display design is that which concerns how display elements should move in response to changes in the aircraft situation. Experimental evidence heavily favors the outside-in and fly-from principles. Conventional aircraft instruments, by tradition and by standard, are inside-out and fly-to devices. Contemporary E/O display design has likewise followed the inside-out, fly-to pattern. The research evidence as to the superiority of outside-in and fly-from is so pronounced that it cannot be brushed aside. In terms of interpretability, speed of response, and ease of learning the aircraft-reference display is to be preferred. On the other hand, it would be disastrous to mix aircraft-reference E/O displays with earth-reference conventional instruments in the same cockpit. It would be only slightly less horrendous to have aircraft-reference displays in some aircraft, and earth-reference displays in others. At the risk of seeming to make the impractical suggestion that the tail wag the dog, we recommend that any E/O display standards committee re-examine the merits of the two systems. E/O displays offer enormous promise in the presentation of flight and navigation information. It seems a pity to dissipate some of this advantage at the outset by selecting a less desirable form of display dynamics. This potential gain must be weighed against the attendant disadvantages of redesigning existing electromechanical instruments and retraining a generation of pilots. The problem of adaption for experienced pilots is not as severe as some have supposed, but it is still a formidable barrier.

We believe that the best ground on which to try the issue is the head-up display. If there is any basic incompatibility between an outside-in display and an inside-out visual world, it would certainly manifest itself on a head-up display in which the two reference systems were superimposed. If it is possible for the pilot to reconcile the two on a head-up display, there will be a very strong argument for re-opening the inside-out *vs.* outside-in issue for the whole cockpit. If not, then the matter should be put to rest and the inside-out principle should be standardized for E/O displays as it is presently for other instruments. While it may be a bit too simple to propose that the principle of outside-in stand or fall on this one test case, we do believe this is the most direct and efficient way of reaching a solution. The development of E/O displays is advancing too rapidly to wait for the result of any protracted program of experimentation and reevaluation. In this connection we also suggest that the suitability of the frequency separation principle (as proposed by Fogel,

Roscoe, and others) be tested experimentally to see if it offers a feasible compromise solution.

The issue of contact analog *vs.* symbolic displays has also received considerable attention. The scheme of spatial ordering of flight control displays implies the need for some degree of pictorial realism. Except for televised displays of the real world scene, the contact analog represents the purest form of pictorial display. At the other end of what Carel (1965) has called the *continuum of literalness* is the purely symbolic display. Experience has shown that neither extreme is satisfactory for the display of flight and navigation information. The contact analog is deficient in the quantitative information needed for accurate flight control and in the lack of a scheme for handling the non-spatial parameters of flight. Symbolic displays, on the other hand, suffer from the lack of a natural integrating framework which corresponds to the coordinates of the aircraft and earth environment. They also require, because of their abstract and symbolic nature, too many transformation steps in the processing of information. Contemporary display designs reflect a *de facto* agreement that a compromise solution is called for. The E/O display should be basically pictorial, but it must be augmented with symbolic and quantitative indications to provide a more complete view of the situation than can be obtained from purely visual cues in the external world. It is equally, and perhaps even more, important that the display have dynamic fidelity. The movement of display elements and their dynamic relationships must follow the laws of motion and perspective which govern their counterparts in the external environment.

While this exposition has been necessarily sketchy, we believe it contains the rudiments of a workable design philosophy for E/O displays. Certain basic decisions still must be made by a standards committee, and further experimentation will be required to clarify certain points and develop additional details. We do not claim that the view expounded here is unique, nor do we claim that it represents the consensus of those active in the fields of research and design. We have tried, however, to summarize the best thinking on the subject and to find a balance between theoretical and practical considerations. From our survey of present E/O displays we also believe that the principles set forth here are indeed those embodied in the most successful of these designs and, therefore, represent the best of current practice.

FORMAT AND PLACEMENT

The arrangement of symbols on a display is related to questions of structure and ordering. That is, if the display is pictorial and structured in real world coordinates, the location of symbols which represent real world objects will be dictated by the location of those objects in the external visual field. Thus, by the very act of selecting a horizontal or vertical situation framework for the display, the designer imposes upon himself a certain format and arrangement. As a further consequence, he must also adhere to certain movement relationships and directional senses. Thus, the vertical (Y) dimension of a VSD corresponds to up and down in the real world, and the horizontal or lateral dimension (X) corresponds to right and left. On a horizontal situation display the vertical (Y) dimension corresponds to North-South or movement along the flight path, depending upon the orientation of the display. Similarly, the lateral or X dimension of the HSD corresponds to either East-West or right-left. The relationships may be expected to hold regardless of the plane in which the display is situated in the aircraft.

However, not all the symbols on a VSD or HSD stand for real world objects, and some are not expressible in the spatial axes of the display system. For these items the designer now has some freedom of choice about where they will be situated, how they will be oriented, and in which direction they will move. He has some freedom, but it is not complete. The basic spatial or pictorial format of the display imposes certain rules and compels the designer to find a position and motion for the non-spatial symbols which will be compatible with the overall display framework and pattern of movement. He must also achieve, insofar as the basic display format permits, an arrangement which is optimum in terms of efficiency of use. It is to these concerns that this section is addressed.

Foster (1966) points out that, in general, format or spatial coding is effective not just in the rapid location of certain items or classes of information but also in tasks which require the integration of various items of information. One of the pilot's basic tasks, even with a highly compact and integrated display such as a VSD or HSD, is the systematic scanning and check reading of a number of indices of performance. An orderly arrangement of these items can greatly facilitate this task. Foster cites a study by Bruner *et al.* (1956) who point out a number of disadvantages of random spatial arrangements as compared to ordered arrangements. A random arrangement makes it difficult for the observer to follow an efficient strategy on the sequence with which he samples or tests the displayed items. The random arrangement makes visual search for a particular item more difficult. Furthermore, random arrangement makes it more difficult for the observer to keep track of the items which he has sampled or tested and those he has not. In general the random arrangement also is

less conducive to creating a strategy for the systematic observation of attributes or dimensions. An orderly arrangement, which is to say one in which items are grouped by class and arranged according to use, will overcome these difficulties. It will also tend to emphasize similarities which might otherwise go unrecognized and help to make differences apparent. From the evidence examined Foster draws the general conclusion that spatial organization of information assists in the integration of information and also in the storage and retrieval of information. Further, the more one is able to adapt the technique of display to the relevant characteristics of the information the more readily can the operator be expected to respond to the information or take it into account.

In general, the focus of attention on a display is at the center. For an inside-out display this point stands for the vehicle itself. On an outside-in display it usually represents the index of desired performance or null reference for one or more variables of vehicle performance. Since the display center is the reference point for the spatial analog, it is generally wise to keep this area free for the interplay of indices which are related to the coordinate axes of the display and the spatial reference system. Indices for other variables not directly related to the spatial analog should not be allowed to intrude into this area nor to interfere with the interpretation of spatial indices moving with reference to the point. More specifically, the center of a VSD should be reserved for attitude and steering information, and it should not be used as a reference point for altitude, airspeed, time, and the like. On the HUD the point which stands for the aircraft, be it the center of the display or the moving aircraft symbol, should have a free zone around it.

In the case of map displays it may not always be practical to follow this rule. Cartographic information should not be obliterated or erased if it happens to fall at the aircraft position. Quite the contrary, it is often very important to know exactly what point on the earth the aircraft is now passing over. The best solution here seems to be use of some coding technique such as color or brightness to allow the operator to differentiate between two symbols or items of information which are spatially coincident. This same solution should be applied to any display on which two indices may happen to overlap. Such may be the case on a VSD where the impact point symbol and the steering symbol, both referenced to the aircraft symbol, can be coincident. It is highly important that neither of these symbols obscure the other and some form of supplementary coding must be used to permit them to be perceived separately. As a general practice overlap ought to be avoided unless doing so would violate the rules of the spatial analog. In the cases just cited of the impact point and the steering symbol or the aircraft symbol and the geographic location, overlap must be accepted. But any two symbols which do not of necessity have to be related to the same point should be situated so that their paths of movement do not cross. This is particularly important for any symbol which does not fit within the basic reference framework of the display.

The usual, and best, solution is to locate such supplementary indicators on the periphery of the display. Depending upon the size of the display and the viewing distance these locations may or may not lie in the cone of central vision. In most cases they will. Thus, the term periphery, as used in this context, does not refer to peripheral vision but simply to the perimeter of the display area. Parenthetically, we might mention that the literature contains several proposals for peripheral vision displays either as supplements to the basic display or as ways of presenting items such as speed or closure rate which are not directly related to the coordinates of the display system in the operator's direct view. We will not pursue the subject here except to note that peripheral vision displays offer some interesting possibilities that merit more investigation.

For VSDs it is customary to display altitude and airspeed indicators on the display periphery, since these quantities are not conveniently expressible in the basic display coordinates. Other indicators often located on the display perimeter are roll angle, heading, vertical velocity, angle of attack, and discretes. Roll angle, of course, is directly related to the reference system of the VSD, being expressible as a rotation of the horizon line or aircraft symbol. The roll scale is usually placed on the periphery since it is a supplementary index and since it is desirable to keep the display center as free as possible. Considerations for the placement of each of these indicators are discussed below.

<u>Altitude</u> - Altitude scales and indicators should be vertically oriented in conformance with the general principle that up on the display means up in the world and down means down. For the same reason, the higher values of altitude should be at the top of the scale. Except perhaps for helicopters, the altitude scale should be located on the right side of the display because of the general practice, deriving from the standard arrangement of separate indicators, which calls for altitude on the right and airspeed on the left.

<u>Airspeed</u> - On current E-O displays airspeed scales are oriented either vertically or horizontally. There is no inherent reason to prefer either location, since the speed is not directly related to either the horizontal or vertical dimension of the display. We tend to favor orienting the airspeed scale or indicator vertically and placing it on the left side of the display for two reasons. First, this conforms with the standard instrument practice, mentioned above, which calls for altitude on the right and airspeed on the left. Second, placing airspeed on the side of the display frees the top for the indicators such as heading or roll angle which should be oriented horizontally. If oriented horizontally, the airspeed scale should read from left to right. There is some question about the proper directional sense for a vertically oriented

airspeed scale. We will not go into it here since it is not really germane to format. It will be discussed in the next section which deals with the design of individual symbols.

Roll - The location of the roll scale and pointer is a moot point, and no symbol has been more migratory. Over the years it has been located at the top, at the bottom, and at the side of the display. Current USAF practice is to place the roll scale at the bottom on conventional attitude indicators, and the newly issued USAF standard, MIL-STD-884, calls for this location on K/O displays as well. Current Navy practice favors placing the roll scale at the top. This is also the position of the roll scale on all the VSDs analyzed in Chapter III, except for the IHAS display which has it at the bottom. The placement of the scale is not just a matter of opinion; it has, curiously enough, a relation to the concepts of fly-to indicator. For example, if the aircraft is rolled right the horizon line will rotate counterclockwise and the roll pointer will be displaced to the left. The proper corrective action is roll the aircraft counterclockwise, i.e., back to the left, which is to say that one must fly-to the roll point position. If the roll pointer is placed at the bottom of the display in the same situation, it becomes a fly-from indicator. That is, in a right roll the roll pointer will be displaced to the right. The corrective action is not to roll the aircraft to the right toward the symbol but to the left. The roll pointer must be flown from its displaced position back to the center roll reference. Those who favor the bottom location point out that the displacement of the pointer agrees with the direction of roll or turn; displacement to the right indicates roll or turn to the right. This is true, but it causes the roll pointer to conflict with the motion of all other attitude and command indices on an inside-out display. We believe consistency of display dynamics is the overriding concern; and we conclude, therefore, that the roll scale and pointer must be placed at the top on an inside-out display. This location has two secondary advantages. On direct view displays placement at the top removes the pointer and scale from the ground texture or other ground elements which might tend to clutter or obscure the symbols. On head-up displays used for landing, the runway symbol and the real world landing site tend to appear in the lower half of the display. Locating the roll pointer and scale in this same area might tend to create interference between the symbols and render reading difficult. Placing the roll pointer and scale at the top of the display avoids this problem.

Vertical Velocity - Vertical velocity is an altitude-related item, and therefore it should be oriented vertically to adhere to the general rule which states that up means up and down means down. The scale should be arranged so that position values of vertical velocity (climb) are arranged in ascending order up from the center of the scale, and negative values (dive) in descending order from the center of the scale downward. As an altitude related item, it should be placed on the right side of the display.

Heading - For obvious reasons heading scales should be oriented horizontally. Three locations are possible. Some current K/O displays place the heading scale along the horizon line, which permits it to be read in relation to the aircraft symbol and the steering symbol. This location has some disadvantages. It tends to clutter the center of the display with scale marks and alphanumerics. The displacement of the horizon line in pitch and roll during maneuvers makes the scale difficult to read. Further, since the horizon line may be out of view in extreme climb or dive maneuvers, it becomes necessary to repeat the heading scale at intervals of 30 or 45 degrees throughout the pitch range. Finally, with the heading scale on the horizon and/or supplementary pitch lines it is necessary for the operator to search for the scale to read it. To overcome these disadvantages, some designers locate the heading scale in a fixed position relative to the display framework, either at the top or bottom of the display. The upper location has the advantage of being an area relatively free of textural elements which might interfere with reading of the scale. It is also possible on displays where the scale rolls with the horizon to use the roll pointer, which is in the same location, as a heading pointer. This approach is used on the DVI on the F-111B. This solution has the major disadvantages of placing two somewhat unrelated scales in proximity and of tending to fill up the top portion of the display with symbols. Location at the bottom of the display is another solution. We tend to favor this location because it creates a good balance of peripheral indicators: airspeed on the left, altitude on the right, roll at the top and heading at the bottom. Possible interference by ground texture elements can be overcome by creating a free zone around the scale into which other symbology cannot penetrate. None of these locations, however, is clearly superior to the others; and the optimum situation for the heading scale will depend upon the particular display, the importance and frequency of use, and the presence of other symbols. If it is deemed necessary to select a standard location, we believe the bottom of the display is to be preferred.

<u>Angle of Attack</u> - Angle of attack is a pitch-related variable and should, therefore, be vertically oriented to be compatible with real world coordinates and with control motion. The usual solution is to place it on the left half of the display often near the left wing of the aircraft symbol. This choice seems sound for several reasons. For landing, especially carrier landing, angle of attack is used to control speed. Location on the left is, therefore, consistent with the general scheme of airspeed on the left, altitude on the right. Location on the left half of the display is also consonant with the standard arrangement of separate cockpit instruments in Navy aircraft, where the apexer is situated on the left side of the instrument panel. Placing it near the aircraft symbol, which is the pitch reference for inside-out displays, facilitates relating these two variables.

<u>Discretes</u> - It does not seem possible to arrive at any standard scheme for the location and arrangement of discrete indicators. The number, variety and possible combinations are quite large. Since they are often supplementary in nature and unrelated to the reference system of the display, the usual practice is to put them in some sufficiently prominent location compatible with other symbols. There are several criteria which may be helpful in selecting a site. Generally, the more important the information conveyed by the discrete, the closer it should be to display center. If the discrete is related to some other display symbol or variable, the discrete should be located in proximity to it. If the discrete conveys any information about position or direction or if it entails control action in some direction, the location should be consistent with the general directional sense of the display reference system. The discrete should be located so that it neither obscures nor is obscured by other important symbols.

For horizontal situation displays relatively few peripheral indicators are used. The entire display surface is kept relatively free of extraneous information so as not to interfere with the reading of cartographic or tactical symbols. The most common peripheral scale is a compass rose, which is either generated electronically or inscribed around the rim of the display. The compass rose is, of course, directly related to the HSD reference system coordinates, and its peripheral location does not derive from the fact that it is out of context on the display. The perimeter is used because it permits a scale of the greatest length and, hence, the widest spacing between scale divisions and the greatest vernier reading accuracy. Symbols denoting heading, course, track, and bearing to target or navigational aids should be so situated that they can be read in relation to the compass rose. If a heading or track line passing

through the aircraft symbol is used, it should be extended to the perimeter of the display so that it can also be read against the compass rose. Supplementary indicators, such as to-from or digital readouts of course, Tacan radial, or navigation and frequency, should be placed so that they do not interfere with the reading of map information. The best solution is to locate these items just outside the boundary of the display on the equipment case.

Apart from the specific recommendations given above, there are a few general guides which will assist in matters of format and placnment. Symbols should be located and grouped in conformance with the expected patterns of use. Indicators which relate to each other or which are used at the same time, even though otherwise unrelated, should be placed together. Thus, in landing, the pilot must not only know his altitude but also how fast it is changing. This argues for putting the altitude and vertical velocity indicators in adjacent locations. Similarly, airspeed, angle of attack, and pitch cues should be grouped for landing since they are interrelated items. In a weapon delivery situation, the steering commands to the target and time or range are items which the pilot must read simultaneously. While both relate to the general situation, they are not directly related to each other. Nevertheless, since the pilot must use these two indications at the same time, they should be placed in proximity to each other.

The importance of a given item of information may also serve as a criterion for its location. The center of the display is the center of the operator's attention. This suggests that the more important the item is to the pilot's task, the nearer it should be to the center of the display. This criterion, however, should be applied with caution. The center of the display is intimately related to the display reference system; it is the point about which the pilot interprets his situation and orientation with respect to real world axes. The intrusion of other information, however important, which is unrelated in its nature or motion to the basic reference system may interfere with orientation and control. Care should be taken, therefore, in introducing into this area items which are unrelated to the spatial axes of the display, especially if they are moving indicators. It is also worth noting that, even with displays which subtend rather small visual angles, pilots tend to fixate on the center of the display to the exclusion of items located in the periphery only a few inches or degrees away. This habit is encouraged by displays which concentrate too much of the important information in the middle. The SAAB pole track display was designed with this very point in mind. The symbology of the pole track encourages a wide scan by having the indicators of attitude, flight path and altitude radiate away from the display center. To interpret the display it is necessary to scan laterally and vertically in order to perceive the situation as a whole. Thus, it would appear that some dispersal of indices within the display field is both necessary and desirable and that location of individual items should be dictated by a balance between importance and the need to avoid fixation at display center.

As pointed out above in connection with scale and pointer indicators on VSDs, the placement and orientation of symbols should be compatible with real world coordinates and with system dynamics. This is particularly important for symbols which move. We will not repeat the rules of motion since they have been made sufficiently clear. However, we do wish to emphasize the influence of the dynamic aspects of the display on format. All of the details of format and placement cannot be worked out from a static picture of the display. It is necessary to see the behavior of the symbols dynamically. As Carel (1965) points out, the static appearance of competing displays is often quite similar. It is only when they move that the striking difference between an organized display and a bag of worms becomes evident. As a practical matter, however, it is often difficult to evaluate display dynamics in a timely fashion since design preceeds the building of hardware. In this connection, the method used by Austin *et al.* (1967) offers exceptional promise. They describe a technique which uses time-lapse photography of a computer driven mock-up of the display and its movable elements to derive a synthesized motion picture of the display in action. The technique is simple and relatively inexpensive, and it has the great virtue of permitting the designer to see the display in a dynamic mode prior to prototype development.

Related to the topics of placement and format is the problem of *clutter*. Clutter is like sin; everyone agrees that it is bad and should be eliminated, but there are several views of what constitutes clutter and how it is to be avoided. Clutter in the common sense refers to a confused collection, a crowded or disordered array. This idea lies at the bottom of the definition of display clutter which says that clutter is a function of density, redundancy, overlap, and interference. A display, by this definition, is cluttered when the grouping and arrangement of symbols is such that separate items are hard to sort out or that the parts interfere with comprehension of the whole. This is largely a subjective judgment, and what may be a tangle for one person may seem perfectly comprehensible to another. Estimates of clutter seem to be largely a function of familiarity. Some of the displays shown in Chapter III seem, at first glance, to be overcrowded and confusing. Experience with the display, or even just a more detailed examination, will cause some of this feeling to disappear. As one perceives the rationale behind the symbols and their placement and as one relates the format of the display to specific tasks or flight situations, a sense of pattern and order begins to emerge. However, these are still subjective and perhaps even aesthetic judgments.

Some investigators have attempted to place the determination of clutter on a more objective footing, though still retaining the basic definition of clutter as density, overlap and interference. In information theory density can be defined as the number of bits per area, including redundant items. Clutter occurs whenever density exceeds human channel capacity, which is to say whenever information must be processed along more than seven

or so channels simultaneously. Noise, irrelevant information, is also a factor; and whenever certain noise-to-signal ratios are exceeded or whenever noise exceeds a certain absolute amount, clutter will occur. A clutter-free display is one on which the desired information can be sorted from the noise and on which the amount of information to be handled at any one time does not exceed channel capacity.

The emphasis on relevancy should not be overlooked. The presence of irrelevant information is a source of distraction and makes the perception and processing of that which is relevant all the more difficult. In terms of display dynamics irrelevant information makes for a busy, or busier than need be display. This criticism is often raised in connection with the dense and active ground texture elements of contact analog displays. One of the methods often suggested to relieve the problem of noise and irrelevancy is color coding. Color, if wisely used, would permit the operator to sort information by class or use and, thus, to select from a rather rich array just that which is relevant to his immediate purpose. Other coding techniques, such as shape, shade (brightness), and position might also be expected to be of help.

Poole (1966) describes two efforts to derive a mathematical description of clutter, defined as symbol overlap and interference. He points out that a certain amount of clutter is inherent in all displays. The problem is to determine at what point it becomes objectionable or it interferes with performance. This is difficult to do because clutter depends on a number of factors: the randomness of the data, the task of the operator, the number of observers, and the time available for observation. With randomly placed symbols, clutter can be stated objectively as the amount of symbol overlap occuring on the average. Poole cites an analysis by Whitham (1965) using a square matrix of M possible symbol positions and N randomly placed symbols. Whitham's analysis did not take into account the fact that symbols are not usually entirely random on most displays and the fact that symbols are usually put on in clusters rather than independently. Poole continues by referencing a theoretical study by Poole and Koppel (1965) which considered the random positioning of a number of items appearing only at discrete positions. If N^2 is the number of total possible symbol locations and K the number of items which can be displayed with a probability of overlap P, and if D^2 is the ratio of the area of the item to the area covered by each resolution cell (symbol location points), they proved that:

$$K \approx \frac{N}{2D-1}\sqrt{\ln\left(\frac{1}{1-P}\right)}$$

This relationship holds within 5 per cent for the normal regions of interest on a display.

Other designers and experimenters with whom we have talked contend that density and overlap have very little to do with clutter. They define clutter as anything that is not in the display frame of reference or anything that does not lend itself to incorporation in a common frame of reference. This definition seems to turn around the notions of contextual and dynamic consistency and relates to the Gestalt psychology principle of common fate. A display will be clutter-free when its elements are consistent in their behavior with their real world counterparts and when they obey the pertinent laws of perspective and motion. This entials both pictorial and dynamic realism. A display without a common frame of reference cannot exhibit such realism because it obeys no natural set of principles. If an element which is not compatible with the display context is introduced, it becomes an alien and distracting feature because it conflicts with, and disrupts, the basic pattern.

Finally, there are some who define clutter in functional terms. Clutter in this sense is any information which is not usable or any feature of a symbol which detracts from its being used for the purpose intended. Thus excessive motion or jitter would be a cluttersome factor. So, too, would be an excessive symbol size or an inappropriate use of color. These persons also maintain that factors such as the number and placement of symbols will determine clutter. This definition can be summed up as "too many symbols with too great a prominance moving too sensitively or too close together". At bottom this definition appears to be a combination of the ideas of relevancy and density, and so it is probably not unique except in its emphasis on utility and functional suitability.

We began the discussion of clutter with a simile; we shall conclude with another. All of these definitions are like the blind men and the elephant. Each is correct, but each describes only a part of the beast. Density, overlap, and interference are certainly factors which contribute to clutter. Too much information and too crowded a presentation cannot be used efficiently. Noise and irrelevancy also play a role. An operator cannot use a display on which he cannot find the information appropriate to his purpose. Consistency, both internally and with the external world, is likewise important. The interpretation of a display requires that there be a pattern and that the elements behave according to operator expectancies. Finally, of course, use must be considered. The appearance of a display is not so important as how well the operator can perform with it. These definitions are like the blindmen's elephant in another respect. All turn around subjective judgments of an observable phenomenon. This does not necessarily deny their validity, but the lack of an objective basis does make the evaluation of displays and the formulation of criteria difficult. Analytical and empirical studies of clutter and measures to overcome it are badly needed. A research program directed to these ends would do much to improve the quality of future E/O displays.

TOWARD A COMMON LANGUAGE

To this point we have touched upon the formal and structural aspects of displays and upon their dynamic properties. We have also reviewed the theory of information coding and the application of specific coding techniques to display design. These are elements of a more specific problem to which we must now address ourselves since, ultimately, a standards committee must also come to some decisions in this area. To be truly effective devices for broad service use, E/O displays must develop a common language. This implies more than standardization of structure, format, and dynamics and the delineation of criteria for the application of certain techniques. It also entails creation of a common symbol alphabet and development of the rules of use - the grammar and syntax of symbols so to speak. That is, certain conventions about symbology must be established so that there is consistency from display to display in the mode of expressing information. Our purpose here is not to design an ideal display; there is no such thing. Neither is it our intention to force symbology into a common mold which precludes variation and individual expression. Our aim is to see how far we can go in synthesizing research and design, theory and practice, to form a set of conventions which will still be flexible enough to permit variation to meet particular needs and sufficiently permissive to encourage improvement and future growth.

Our approach to this matter involves two steps. First, we shall take up considerations which apply to the design of certain classes of symbols. Second, we shall deal with the design of individual symbols to convey the information identified in Chapter III as requirements for display. We must confess that we enter on these tasks with some trepidation since both require the exercise of judgment which may not be properly ours to make. We are, in effect, expressing our own opinions, but in doing so we shall try not to slight other points of view and to retain as much generality as such an exercise allows. We also do not mean to imply that the selection of an E/O display symbology is a simple task. Many factors come into play. We can do no more than suggest them in a brief treatment such as this. Our attempt shall be to isolate those items about which there is sufficient research or common agreement to warrant establishing a convention or standard. For those where there is still some doubt or controversy we shall indicate what still needs to be done. We shall also point out those areas where it does not seem wise to impose a standard.

General Types of Presentation

Four types of presentation will be examined here: null symbols, scales and tapes, digital callouts, and discretes. These categories are not all-embracing; there are some presentations which may not belong to any of the four. This is probably true of textural elements of a contact analog display.

There are also some symbols which will not fit neatly into one category or another and so are hybrids. This is the case with some moving tape scales which have both status and command pointers and, thus, are a cross between a scale and a null symbol. These four categories do, however, cover most of the symbols found on E/O displays and constitute the most important types of information presentations.

Null Symbols

A null symbol is one which presents a statement of performance error as a difference in the position or orientation of the indices of desired and actual performance. The difference may be either with respect to each other or with respect to an independent reference system. Since the object is to reduce or null the error by aligning the indices, a null symbol is one which presents the operator with a compensatory or pursuit tracking task. As it is stated, this definition could be applied to scale or tape presentations also, in that the alignment of a lubber line or moving pointer with a particular scale value is a tracking task. Because we mean to reserve discussion of scale presentations until later, we shall arbitrarily exclude them as null symbols by stipulating that null symbols are those which move through an interval that is not differentiated or subdivided and are not themselves subdivided.

The choice of the appropriate null symbol is intimately related to machine dynamics, human response characteristics, and human transfer functions. These are vastly complex subjects which we cannot treat adequately here. The best short treatments of man-machine dynamics can be found in standard human factors references such as McCormick (1964) and Morgan *et al.* (1963). Our summary of the topic follows the outline of the latter source.

The operator, the vehicle, the control, and the display constitute a closed-loop system in which operator input is the information presented on the display and operator output is the control action he takes. Feedback about vehicle response, through the display, provides the operator with an indication of how to close the loop. That is, the operator tracks the null or error symbol. In designing a display one must make a basic decision whether to employ pursuit or compensatory tracking. This choice will be dictated by factors such as the complexity of the desired operator output and the dynamics of the vehicle. It will also be influenced by display characteristics such as the size of the display and the clarity (*i.e.*, the definition and structure) of the background. Generally, a pursuit tracking display must be of greater size and have a more clearly defined background reference system. The point to be emphasized is that neither a compensatory nor a pursuit tracking display is inherently better in terms of task ease or in terms of the accuracy and consistency of the human output it fosters. Each is preferable in certain circumstances and for certain applications. Standardization in this area seems neither possible nor desirable.

Another major consideration which will influence the design of the null presentation is the characteristics of the data input. The nature of the input, the data repetition rate, and the presence or absence of anticipatory information all must be taken into account. One of the major factors is the kind and degree of information processing which takes place prior to presentation to the operator on the display. Command data may be presented as simple error, or it may be smoothed, filtered, quickened, or treated in a variety of other ways. One of the most often debated issues in connection with command presentations is that of simple error presentations as opposed to more highly processed forms such as quickened or smoothed indications. Quickened displays have the major advantages of simplifying the tracking task, limiting the detrimental effects of contol reversal errors, promoting an asymptotic approach to the command value without overshoot or undershoot, and making the system much less dependent on human performance. Some quickened displays have the disadvantages of not providing the operator with information about the actual state of the system and of making it difficult or impossible for the operator to execute the maneuver in any other manner except that programmed into the display. A simple error system has neither of these disadvantages, but tracking performance is more difficult and more dependent upon operator skill. Smoothing (*i.e.*, averaging over time) the command input will help reduce some of the variability of simple error displays, but it has the major drawback of introducing a lag or delay in information about the present state of the system. An E/O display standard should permit the designer a latitude of choice on data input characteristics.

A related concern is that of selecting an optimum scale factor for the null symbols of the display. As a general rule, precision of control increases with an increase in scale factor, *i.e.*, as the null symbol becomes more sensitive. Past a certain point, however, the sensitivity will exceed the operator's capacity to track the symbol, and he will overcontrol the system or "chase" the symbol ineffectually. A reduction in scale factor below optimum sensitivity will promote stability of control but at the price of a decrease in precision. The selection of the appropriate scale factor will be determined primarily by the accuracy requirements of the mission, the error of the data sensing and processing equipment which drives the symbol, and the impact of symbol sensitivity on operator work load and tracking ability. Scale factor is, therefore, more or less peculiar to each aircraft and not standardizable. However, once a scale factor has been arrived at, it should be applied consistently on the display. That is, the scale factor along each of the coordinate axes of the display reference system should be identical or nearly so. Further, the scaling of any symbols which present information expressible in the basic reference system coordinates should be the same as the scaling of the display as a whole. Thus, horizontal steering commands on a VSD should have the same scale factor as heading information and the horizontal field of view. So too, the scaling of pitch information and vertical steering commands.

While it is not possible to fix a scale factor and rate of symbol movement which will be optimum for all displays, the characteristics of electronic generation do impose an upper limit on the rate at which a symbol can move on CRT displays. If symbol motion exceeds a certain limit, strobing will occur. Strobing is an optical illusion whereby moving objects appear to change speed, stop, or reverse direction. It arises from the fact that multiple images are formed. The following analysis and example of strobing effects are adapted from Williams and Kronholm (1965).

Experimental evidence indicates that strobing begins to take place in an iterative image generation system when the object of interest moves a distance equal to its maximum dimension in one frame interval, *i.e.*, when in successive images an object changes position by an amount equal to or greater than its linear dimension measured along the line of movement. At standard TV rates, for example, the frame rate is 30 cycles per second, and the frame interval is 0.033 second. The maximum rate of movement before strobing will occur is given by:

$$R = l/T = l/0.033 = 30l \text{ units/sec}$$

where,

R = maximum rate of movement before strobing occurs

l = number of scale units corresponding to the symbol dimension

T = frame interval

This expression can be used to determine either the maximum input rate of change for a given scale factor (value of l) or, conversely, the minimum value of l for a given rate.

For example, assume an altitude error symbol moving vertically on a VSD whose frame rate is 30 cycles/second. Assume also that the symbol has a vertical dimension, height, h. The most sensitive scale factor (the minimum value of l) for such a symbol can be determined if one knows the maximum vertical velocity likely to be encountered. Using the extreme case of 18000 feet per minute (300 feet per second) for vertical velocity:

$$\begin{aligned} l &= RT \\ &= 300 \text{ ft/sec} \times 0.033 \\ &= 10 \text{ ft/unit of symbol height (h)} \end{aligned}$$

This is to say that if the altitude error symbol is 0.1 inch in height, the most sensitive scale factor for the symbol is 100 feet per inch if strobing is to be avoided.

[illegible]

The two most prominent questions in connection with the design of scales are whether to use a fixed or a moving scale and what scale factor to use. The factors which determine the optimum scaling of a display were discussed above in relation to unit symbols and need not be repeated here. It is a tempting idea in this to seek standardization, and attempts to establish optimum scale factors for certain types of displays (notably altitude scales) are often mentioned as pressing research needs. Because scale factor depends upon so many other variables which are not themselves standardizable, we do not believe that any acceptable general solution is attainable nor practical to seek.

The question of fixed or moving scale was raised earlier in connection with the more general issue of inside-out or outside-in. The topic has been intensively investigated, especially in connection with altimeters, but the conclusions are somewhat mixed. In general, experimental evidence shows that the fixed scale, moving pointer configuration leads to superior performance. The chief reason for this seems to be that the operator is able to associate a unique pointer position with a unique value, which makes check-reading and monitoring easier (Baker and Grether, 1954; Wulfeck et al., 1958). Another reason for the superiority of the fixed scale and moving pointer derives from the fact that tracking is easier and more accurate with displays on which the moving part represents the vehicle.

However, factors other than performance have to be considered. If the range of values to be displayed is large, the moving tape type of indicator has an advantage. It permits a sensitive scale factor to be used for that portion of the scale or tape in view and, hence, better accuracy of reading and control. At the same time the scale covers a great range which allows it to be used throughout large excursions. These were some of the reasons underlying the adoption of the vertical tape scales used extensively by USAF. A good summary of the USAF development program and the rationale of moving tape scales can be found in Brown (1959).

The fixed scale, moving pointer configuration seems best suited to situations in which the range of values to be covered is relatively small. Such is the case with displays for approach and landing, where the speed range may be only 100 knots or so and altitude may be limited to under 2000 feet. Because the length of a fixed scale is limited by display size, it is not possible to have a scale which both covers a large range and has sensitive scaling unless some supplementary technique is used. This was the problem faced much earlier in connection with circular altimeters where the solution was found to be a counter-pointer device or - preferably - a counter-drum-pointer. (See Heininger, 1964 and Hill and Chernikoff, 1965.) Essentially, altimeters of this sort consist of a digital readout of altitude to the nearest 1000 feet and a dial and rotating pointer for vernier reading within the 1000-foot range. This same solution could be applied to V/G displays by unwrapping the dial to create a linear scale.

Despite the amount of investigation, there are very few firm conclusions to be drawn. Fixed scales and moving pointers seem best for displays for landing and other mission phases where performance is limited. For more widely variable situations either the moving scale or the equivalent of the counter-pointer may be better. There is a real need for additional research in the use of scale indicators on E/O displays. Much of the research that has been done has been with conventional instruments, which are constrained by mechanical feasibility. E/O displays provide much more freedom, and it may be that some variation of one of the two basic types will be developed to combine the advantages of each.

The design of the scale itself, whether fixed or moving, has also received considerable attention, and the principles of good scale design are well known. The following summary is adapted from Morgan *et al.* (1963).

1. Scale numbers should be in progressions of one, two, five or decimal multiples thereof. Two is somewhat less desirable than one and five.

2. Between numerals there should not be more than nine graduation marks, i.e., ten intervals.

3. Normally, scales numbered by decimal progressions (1, 10, 100, etc.), and subdivided into ten graduation intervals, are superior to other scales. (Later confirmation of this can be found in Kelso, 196[illegible], who indicates that the use of nine graduation marks, ten intervals, is superior to either none, one, three, or four.)

4. Generally, interpolation should be avoided; but if space is limited, it is better to require interpolation than to clutter the scale with graduation marks.

It seems reasonable to conclude that these principles hold for E/O displays since they are not dependent upon any particular generation technique, but upon the human capacity to interpret and process information. The same is not true for some other aspects of scale design, such as the design of pointers and scale graduation marks. The problems of drawing fine, sharply defined lines and of providing good contrast are not the same for E/O displays as they are for conventional instruments. It would be unsafe to generalize from findings based on the use of mechanical indicators read in reflected light or transilluminated. Some research on this matter has been done, e.g., at Nordon in connection with the IEVD (see Williams and Kronholm, 1965), but much more will be needed. While not a pressing concern, it is certainly deserving of attention. As a tentative conclusion, we suggest that the most appropriate shapes for pointers on E/O displays are the triangle, the V, or the bar.

In conversation with display designers during the course of this study some additional practical guides relating to scale design were suggested. Although there is little published evidence to support these ideas, we believe they are to be recommended because of their inherent common sense.

As a general rule the peripheral airspeed and altitude scales on earth-referenced VSDs should be roll-stabilized. That is, they should remain fixed with respect to display coordinates and not respond to aircraft roll. These items are not related to the earth coordinates represented on the VSD, and they should not respond along with those which are. Also, the rolling of these scales will make them harder to read.

On a head-up display of the gunsight type the field of view is circular and often rather limited. Vertically oriented scales to indicate airspeed, altitude, and the like are frequently placed as near the limits of the field of view as their length will permit in order to free the center for attitude and steering information. The scale is thus the chord of a circle, which means that the area between the outside of the scale and the limits of the field of view is somewhat cramped. A pointer moving against a fixed scale in this region may be lost from view, especially near the top or bottom of the scale. For this reason it is better to place the pointer on the inside of the scale, i.e., toward the center of the display, and the numerals on the outside. The pointer is the important element of the scale and should always be in view. The numerals on a fixed scale do not change, and so if they should temporarily be lost from view because of lateral head motion, the consequences are not severe. Their position and value are known, and a view of any part is usually sufficient to suggest the whole.

The sensitivity of a scale should be matched to the accuracy of the input information. It is an unnecessary complication of the pilot's task to burden him with a sensitively responding scale when the information driving the indicator is of a lower accuracy. For example, it is all too easy to conclude that the scaling of an altitude indicator for landing should enable the pilot to read altitude to the nearest 10 or 20 feet because the control system permits such accuracy and because the situation requires it. If, however, the combined error of the data sensing and processing equipment is 30 or 40 feet the display cannot be more accurate than that, and it is misleading and dangerous to suggest that it is by dividing the scale into increments of 10 or 20 feet. The accuracy of a system can be no greater than that of its most inaccurate component; and display sensitivity must be selected with the total system error in mind.

The proper directional sense of scale or pointer movement in relation to control action and real world coordinates has been established by experimentation and validated in practice. For VSDs these relationships are as follows. Forward control motion corresponds to up or increase on the scale and up in terms of real world coordinates. Rearward control motion relates to down or decrease. For lateral control actions, right means right or

clockwise rotation, and left means left or counterclockwise rotation. The numerical values on vertically oriented scales should, therefore, be arranged with the higher or positive values at the top and the lower or negative at the bottom. For horizontal scales the higher or positive values should lie to the right and the lower or negative values to the left. The only possible exception to this scheme seems to be a vertically oriented airspeed scale. Experience with the F-111B display (in which we participated) and the IFVD (See Williams and Kronholm, 1965.) suggests that pilots find it more natural and flyable if the normal scale arrangement is inverted and the higher values of airspeed placed at the bottom. The reason for this seems to be the tendency to relate airspeed control to the stick more than to the throttle. Thus, the way to gain or lose airspeed is to push over or pull up, at least for small speed variations. This is a small but troublesome problem, and it deserves some attention. We do not believe the direction of airspeed scale or pointer movement should be standardized without the benefit of additional experimental evidence and flight test experience. For all other scales, standardization should be along the lines described above.

Digital Callouts

The pilot's task often requires quantitative and numeric information. One of the great values of E/O displays is their capacity to present multiple digital indications whenever called for and wherever desired on the display surface. This capability should be exercised with caution, however, and the use of digital callouts on E/O displays should be guided by the same rules which apply to other types of displays.

In general, digital indicators are excellent for quantitative readings; they permit minimum reading time with a minimum reading error. They also facilitate setting tasks, where a specific quantitative value must be chosen or a specific input made, although the relation between the read-out and the setting control is sometimes subject to confusion. Digital presentations, on the other hand, are extremely poor for tracking tasks since they are hard to interpret for rate and trend. This suggests that the most suitable applications for E/O displays are for indications which are stable or which change slowly. Some such indications are manually or automatically inserted command values, Tacan or VOR-omni selection, distance to destination or check point, and radio or navigation and frequency. They are also useful as supplements to other indicators. An example mentioned earlier was that of a gross readout of altitude to supplement a scale on which vernier readings are made. Another possibility is a digital readout of course on a navigation display to duplicate the indication supplied by a pointer and compass rose. In this case the digital readout would facilitate check-reading while the pointer served for tracking. Digital readouts most clearly should not be used for rapidly changing or variable information such as time or heading.

Discretes

A discrete indicator presents a statement of fact about the condition of the system or about a condition in the external environment. While it may call for specific action, the discrete is not a quantitative indicator, nor does it call for any proportional or tracking response by the operator. It indicates only that a certain state of affairs exists. The message is conveyed by the simple presence or absence of an indicator. The name derives from the fact that the information exists only in two or so discrete states. E/O displays are particularly suitable for presentation of discretes because of their capacity to generate a wide variety of pictorial and symbolic indices. Also, the E/O display tends to be the center of the pilot's attention; and, therefore, it is a good locus for information which is not ordinarily part of his task but may on occasion require his attention or demand specific action.

Shape, especially if it is pictorial, is useful for encoding discrete information since it offers the advantage of indicating directly the particular situation referred to. If not pictorial, the shape used should at least be readily recognizable. All shape-coded discretes, pictorial or symbol, should be sufficiently prominent in size and location to attract immediate attention. The following examples illustrate the kinds of use to which shape coding can be put for discretes. A wheel or doughnut shaped symbol can be used as a landing gear discrete since the shape is pictorial, and it is also used to shape-code the landing gear control. Thus the pilot has a picture which he can associate directly with the aircraft subsystem and its specific control. The arrow is stereotypically associated with the direction of travel. This shape can therefore be used as a to-from indicator in association with a navigation reference point on a horizontal situation display. The shape here is a mixture of pictorial and symbolic. In range or out of range for weapon delivery is an item for which there is no generally accepted pictorial or stereotyped shape. This information may be encoded by any sufficiently recognizable shape which does not conflict with other symbology.

Color, shade, and flash are most suitable for generic rather than specific indicators. They may also be used to supplement some other code or to create combination codes. Thus, the conventional use of red and yellow as colors to denote warning and caution could be applied to discretes on E/O displays. Here, color serves as a discrete to indicate the nature of the situation rather than the specific item to be attended to. Color or shade might also be used in another way. There is always a question on displays whether the erratic behavior of a symbol is due to display or data input system error. It would be possible for the pilot to distinguish between the two causes if a symbol, such as the steering symbol on a VSD, were coded by color or shade to indicate that the data input is inoperative or out of tolerance. This is analogous to the practice of flagging conventional instruments. Flash coding is an excellent attention-getting device. It also

has the stereotypic association of urgency. Its use with discretes should be reserved for those items which require immediate attention or prompt action.

Alphanumerics have virtually limitless possibility as a coding dimension for discretes. Any message can be stated in compact and easily readable form. The following rules should be observed. The message must be brief. If abbreviations are used, follow MIL-STD-783 and the ANA-261 bulletin. Alphanumerics should not be used for any situation which calls for immediate action; reading takes time, and there is always the possibility of error. Alphanumerics should be used for giving more detailed and specific information than can be encoded pictorially or by other symbolic means. If some other coding technique is suitable and available, it should be used in preference to alphanumerics. It is unwise to combine alphanumeric with flash coding; a flickering legend is hard to read.

There is a final and general point to be made in connection with discretes. Williams *et al.* (1956) point out that there is a long-standing confusion about the term *warning*. It is used to refer to genuine emergencies such as fire, pull-up to avoid impact, or wave-off in a carrier landing. Warning is also applied to indications of potentially dangerous states, *e.g.* low fuel supply, landing gear position, and ECM information. These are really two different classes of information. While this observation applies to all types of displays, it is most pertinent to E/O displays. For the first time we have a device whose information handling capability is sufficiently complex and varied to make it a general purpose source of information about the total aircraft system. Designers and experimenters should give more attention to this application of the E/O display. Of immediate interest is the question of creating four classes of discrete indicators: emergency (Williams and his associates use the term *alarm*), warning, caution, and advisory. As a consequence, it would also be necessary to devise a scheme for allocating this information, by class and item, to the E/O display or elsewhere. Our tentative recommendation is that all emergency items be placed on the VSD along with a master warning and a master caution indicator. To present more than this on the VSD would be to invite clutter.

A more fundamental and pressing need, however, is an investigation of the E/O display as the information center for total system management. Most E/O displays today are deficient in their capacity for self-detection of display system error and out of tolerance situations. Further, E/O displays do very little in the way of presenting information about the health and readiness of other parts of the aircraft system. The flexibibity of symbol generation and the multi-mode capability of E/O displays make it possible to use these devices as a central reference source for callout of data either automatically or in response to operator interrogation. This notion, of course, goes far beyond the matter of discretes. It is raised here because the present practice in aircraft is to use discrete indicators to display the small amount of system-state data that is available.

Individual Symbols

In advocating a common display language some tend to think primarily in terms of a standard alphabet of symbol shapes. Standardization of this sort has much in its favor. In the present state of affairs a given shape may signify one thing on one display and something else, perhaps quite unrelated, on another. This leads to confusion, not only in the evaluation of competing designs, but also in operational use when the pilot transitions to another aircraft with a different display. There is also reason to conclude that a standard alphabet is needed to insure that the most discriminable and appropriate shapes are used for given purposes. Finally, since a display is an aggregate of symbols, there is a need to regulate symbol usage so that the overall effect of the display is harmonious and suited to the intended use.

As desirable as these ends are and as admirable as it is to seek them, we believe the matter must be approached with great caution. Despite the experimental evidence which has been amassed over the years, symbol design still has more the aspects of an art than a science. Personal opinions still come into play, and questions of aesthetics enter too easily into the selection and evaluation of symbol design. There are also less subjective considerations. The characteristics of a given symbol may be optimum if the symbol is looked at in isolation, but in combination with others it may not be so suitable. The number of possible symbol combinations is so large and their interrelationships are so complex that any given symbol alphabet is bound to be inappropriate in some cases. Even if it were possible to arrive at some set of symbols suited to all applications, one might well discover that the symbols were truly optimum for none. A little more freedom in the selection of symbol characteristics might lead to better individual displays.

Nevertheless, we feel we would be begging the question if we did not try to reach some conclusions in this area. The recommendations which follow are only a modest beginning, but we fully anticipate the criticism that we have gone too far. We have made use of research evidence, current practice, and the best advice of designers with whom we have talked. The synthesis is entirely our own, however.

We have by no means exhausted the inventory of symbol shapes, nor have we been able to assign a peculiar symbol to each item of information required on VSDs and HSDs. We have simply drawn up a list of those symbols which ought to be reserved for certain purposes. This usage is not mandatory and the recommendations do not necessarily preclude the use of another symbol for a given purpose provided, of course, that symbol is not also on the reserve list.

Most of the symbols listed are for vertical situation displays. These displays tend to have a much richer variety of symbols, and their need for symbol conventions seems to be greatest. The recommendations for attitude

and steering symbols apply only to inside-out displays. We have not concerned ourselves with outside-in displays or hybrid forms since the suitability of such designs for E/O displays is an unsettled issue.

With the exception of the aircraft reference symbol, we have not included horizontal situation display symbology. HSDs used for navigation consist mainly of cartographic symbols, which tend to follow the conventions used on printed maps. Although discussed earlier in connection with coding, we wish to repeat here for emphasis that the adaptation of traditional map symbology to presentation on E/O displays is a topic which deserves extensive research and prompt attention. As also noted earlier, tactical HSDs already have a rather full standard symbology, but some effort will still be required to extend it to all applications.

As a final point, we recommend that this or any list of symbols drawn up by a standards committee be circulated among designers and display manufacturers for comment prior to adoption. Provision should also be made for a periodic review and update to keep a standard symbol list consistent with the future needs and evolution of E/O displays. The most likely development, it seems to us, could be the development of two sets of symbols, one for fixed wing aircraft and another for helicopters. Rotary wing aircraft have been plagued by a lack of instrumentation appropriate to their performance capabilities. Research is underway in this area, and as new display designs evolve for helicopters it will probaby be necessary to devise new and more appropriate symbols.

Horizon

The basic reference for attitude in the real world is the horizon. Obviously, a line is the appropriate symbol for this purpose. It may be solid or gapped and may or may not extend all the way across the display. It should be longer than minor pitch lines, and distinct in some way from major pitch lines.

Aircraft Symbol

Preferred Alternatives

A number of symbol shapes are considered appropriate for displaying one's own aircraft reference. The desired elements of this symbol are: 1. its <u>pointer function</u> which provides a reference for attitude and perhaps other items such as angle of attack; 2. its <u>gapped center</u> which provides a clutter-free zone to minimize obscuration of other symbols moving in this area; 3. its <u>center dot</u> which establishes a fixed display center reference

point, null reference point, and index mark.

The preferred shape is considered superior to alternates because it is especially good for use with the recommended, steering symbol shape, it provides the least obscuration, and it has pictorial qualities. In regard to the latter the "wings" and "wheels" also afford meaningful vertical orientation cues against a dynamic background.

For HSDs a small pictorial aircraft symbol has the virtues of common usage and universal meaning. It serves as a pointer but does not seriously obscure cartographic or other symbols in the same area.

Pitch Lines

Although the horizon is considered to be the basic pitch reference, incremental marks are needed for more accurate reading. Scale type symbols are appropriate for such use. The selected configuration should be readily distinguished from the horizon. Positive and negative values should be clearly indicated. The lines should not be so pronounced in luminance, size, or rendition as to obscure other symbols or to distract from overall display interpretation. When the horizon is outside the field of view major pitch lines should be readily identified as to value and direction.

Roll Scale

The use of a scale to depict roll is generally accepted. A center reference mark with 10° increments to 30° is ordinarily used. Additional marks at 60° and 90° points may or may not be required.

The real issue is placement of the scale rather than its shape. This was discussed earlier under display format.

Steering

The recommended symbol for steering is both pictorial and compatible with preferred aircraft reference symbol designs. At the null position a complete aircraft symbol results from the combination of respective symbol shapes, *i.e.*, wings, tail, and wheels (or fuselage) are represented when the steering and aircraft symbols are joined.

The preferred steering symbol is a variation of the cross, which is one of the most easily descriminable symbol shapes. Yet, unlike the cross, it is not readily confused with the common stereotype of location or target so often associated with cross symbols. (See also Pathway below).

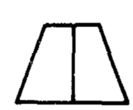
Pathway

The pathway symbol is an index of desired performance and encompasses steering, course/track, and sometimes altitude information. It provides an alternative to the steering symbol shown above. As a shape it is more closely allied with the contact analog concept.

The advantages of the recommended shapes are that they afford an easily discriminable pointer in pictorial form. Deformations can be used to indicate parameters such as altitude and course. Obscuration is minimal at symbol apex.

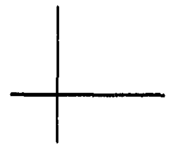
This symbol should be used exclusively as a command symbol, and not as a velocity vector.

Runway/Landing Site



A trapezoidal shape is recommended for representing the runway and landing site, particularly for fixed wing aircraft. Common usage and pictorial qualities are the primary reasons for this selection. The centerline is optional.

Glideslope/Glidepath



Glideslope and glidepath information can be suitably displayed by the illustrated symbol. It is analagous to the ILS cross pointers commonly found on conventional instruments. The horizontal and vertical elements should be capable of independent motion to show separate as well as combined glideslope/glidepath deviation.

Altitude

Either a scale or null symbol can be used. If a scale, the general scale principles previously described should be employed. If a null symbol is desired no common shape has or probably can be meaningfully associated with altitude. Therefore, no recommended shape will be given.

Airspeed

The same options are available here as for altitude. No standard symbol shape is recommended.

Angle of Attack

A scale or null symbol may be used. See altitude. No standard symbol shape is recommended.

Velocity Vector/Impact Point

The velocity vector or impact point symbol indicates the actual path of the aircraft. It should not be confused with an indication of desired performance, such as a pathway or steering symbol, and is most suitably displayed as a small outlined circle or a disc. To be clearly visible against varied display backgrounds and to be prominent in relation to other symbols, the impact point symbol should subtend at least 15 minutes of arc.

CHAPTER V - DISPLAY CHARACTERISTICS

INTRODUCTION

In the two preceding chapters an attempt was made to develop a common display language (insofar as one can be developed) by examining information requirements and display informational content. Such topics as symbol coding, size, shape, and related properties were discussed to determine what general guide lines for standardization might be suitable across displays.

This chapter is, then, the third of three successive major sections. We are now ready to discuss those characteristics of displays that relate to, or result from, the fact that they are either electronically or optically generated devices. The emphasis, however, is not merely on display characteristics *per se* but, even more importantly, on the fact that pilots must use displays under a variety of field conditions. Therefore, we will attempt to air some of the psychophysical issues that affect the pilot's visual task and the design standardization problem.

Of the psychophysical considerations for display design, the most complex and dominant are those of visual perception. A knowledge of visual perception and related interaction effects of physical stimuli is generally desirable and sometimes vital to design decisions. For example, one might ask if an electroluminescent display of low luminance is completely unsuitable for use in a cockpit in a high ambient light environment. Or, is high contrast an effective substitute for low luminance in certain situations? The answers to such questions might well open or close the door to research and development in a given field. Other examples are not difficult to find.

In order to foster a better understanding of the visual perception issues that are so inextricably bound to display characteristics, it is helpful to keep two points in mind.

1. Pilots are quite adaptive and are therefore able to perform more or less successfully, if not efficiently, across a range of poor to good equipment designs. This human adaptability may come to the defense of a marginal design and offset its deficiencies. The consequences of poor designs are, however, not always apparent in the early design stage. Furthermore, deficiencies may not be acknowledged until the situation becomes such that the pilot cannot perform adequately in flight tests or in operational conditions. The degree

to which human factors studies can minimize such deficiencies depends on a number of variables that cannot be treated here.

2. Overdesign is as prevalent a problem as the reverse, although it is probably less serious and more difficult to detect. A pilot is less likely to complain about having ten times the necessary display luminance, for example, than he is about having only half as much as needed. Overdesign tends to waste money and resources. Underdesign, on the other hand, detracts from pilot performance, causing needless effort at best and serious consequences at worst.

VISUAL FACTORS

The importance of visual factors in avionics display design is stressed in this report, partly because we believe them to be important and partly because they characteristically receive less attention than they deserve. Few agencies or contractors seem willing to invest the time and effort needed to resolve visual factor problems of long term or even of more immediate standing. Some of the inertia probably results from the wealth of available data in the visual research field. However, this is illusory. Abundant marginal information may well obscure the need for studies which are aimed at related, although quite different problems. The unaccounted for effects of but one variable can alter the applicability of even the most thoroughly resolved data. For instance, the effects of inadequate display contrast on reaction time or the adding of one more task to the workload of a pilot performing at the limit of his ability are obvious examples of operational variables that can change or render useless otherwise valid predictive data. Less obvious, but equally pertinent examples, are the uncontrolled and non-uniform dispersion of light-emitting sources in the night lighted cockpit or the effects of vibration on visual tasks. Such factors can readily confound design guide minimums. Ideally they should be resolved prior to final equipment design approval.

In a more general view we can note that the risks of extrapolation and generalization from one set of laboratory or field conditions to another are elementary pitfalls which should be well known to the human factors experimentalist. In the same sense that the cowling design for one aircraft may not be appropriate for a similar aircraft, although the same aerodynamic principles apply, a display filter or CRT for one display may not be wholly suitable for a similar application in another aircraft, although the same psychophysical principles apply. In these matters an ounce of human factors evaluative studies are indeed worth a pound of retrofit.

Night Vision

A controversy still exists over the use of red or white lighting in a cockpit at night. Those who favor red light contend that red light, because of its longer wavelength, helps to preserve rod vision for the dark adapted eye. White lighting proponents maintain that the intensity of light is far more important than wavelength. They also point out that reading color coded displays, maps, or controls is confounded by red lighting. The controversy persists because both views are correct, at least in part. A resolution of the issue is to be found only within the larger context of operational requirements and overall system considerations.

The primary question is in deciding how important it is to maintain a dark adapted state. Air Force interceptor pilots, for example, may not be

required to land under conditions comparable to those aboard a dark carrier, but also they expected to hover and land in a dark jungle clearing. To the extent that such statements are correct, dark adaptation may be considered relatively unimportant for them.

Regardless of how important or unimportant dark adaptation may, in fact, turn out to be for a given aircraft mission, a systems approach to the problem is deemed to be advisable. Even pilots having white lighted cockpits may occasionally want unusually good night vision. In such cases a means should be available to allow them to effectively control cockpit ambient light. A need is related to the following considerations. Since light intensity is known to be of more relative importance than wavelength in preserving dark adaptation, a pilot can turn panel and CRT display lights to low intensities whenever appropriate. Practically speaking, however, the effectiveness of this technique is likely to be limited. Cockpit light systems often produce an array of high, low, and intermediate intensity levels which are not systematically related to dark adaptation management. Each display manufacturer is more or less free, within certain constraints, to provide whatever low intensity lighting adjustment range he pleases. Furthermore, his emphasis is likely to be placed on attaining a suitable range of high intensity levels, rather than low, because the high ambient problem is recognized as being more formidable.

The net result of having non-uniform lighting without planned low intensity control is likely to be an ineffective method for establishing dark adaptation. Even if a pilot attempts to dim every light emitting source in the cockpit, he is still required to estimate appropriate intensity levels for a variety of sources. How well this can be done is open to question.

Although admittedly oversimplifying it, the whole problem can be succinctly stated in the following way. If a serious need to preserve dark adaptation is justified, a more systematic approach to the problem can and should be taken.

As a minimum requirement, some effective means to avoid gross disparity between independent light source intensity levels seems warranted. Others support this view. For example, Morgan *et al.* (1963) cite a need for uniform cockpit lighting and suggest a range of 7:1 between the brightest and dimmest indicators or portions of indicators. They also recommend a brightness adjustment control that is continuous through the specified range when dark adaptation is necessary.

The brightest levels recommended by Morgan are generally supported in studies by Spragg and Rock (1948) which indicate a critical brightness level of approximately 0.02 ft L. Rock later (1953) found that the critical brightness level range is between 0.02 and 0.05 ft L. He recommends trading absolute intensity for uniformity, if necessary, and suggests 0.10 ft L as an acceptable level. Note the agreement with Morgan's table (Table 19).

TABLE 19 - INDICATOR, PANEL, AND CHART LIGHTING

Condition of use	Lighting Technique	Recommendations	
		Brightness of markings (ft-L)	Brightness adjustment
Indicator reading, adaptation necessary	Red flood, indirect, or both, with operator choice	0.02-0.1	Continuous throughout range
Indicator reading, dark adaptation not necessary but desirable	Red or low-color-temperature white flood, indirect, or both, with operator choice	0.02-1.0	Continuous throughout range
Indicator reading, dark adaptation not necessary	White flood	1-20	Fixed or continuous
Panel monitoring, dark adaptation necessary	Red edge lighting, red or white flood, or both, with operator choice	0.02-1.0	Continuous throughout range
Panel monitoring, dark adaptation not necessary	White flood	10-20	Fixed or continuous
Either with possible exposure to bright flashes	White flood	10-20	Fixed
Either at very high altitude and restricted daylight	White flood	10-20	Fixed
Chart reading, dark adaptation necessary	Red or white flood with operator choice	0.1-1.0 (on white portions of chart)	Continuous throughout range
Chart reading, dark adaptation not necessary	White flood	5-20	Fixed or continuous

(Adapted from Morgan *et al.*, 1963)

Two special low intensity visual problems arise with the use of E/O displays:

1. The direct view raster display sometimes has symbols, such as an aircraft reference symbol, a roll scale, or fiducial markers, which are painted on the display surface rather than generated electronically. To render these displays red for night use, an aviation red filter is placed over the display, usually on top of the day filter. With the display intensity thus lowered, it can become difficult or impossible to distinguish the painted symbol from the electronically generated background. This is especially true if the ground plane is shaded so as to form a dark zone just below the horizon.

2. Chalmers (1950) found that dim silhouettes are much more difficult to detect when the eye is exposed to dazzle and afterimages resulting from extreme contrast. Kelley *et al.* (1965) cite the above report and warn that fluorescent line written symbols, such as those on projected head-up displays, appear against an almost totally dark background. The use of a red night filter and an adequately scaled intensity control should help to minimize this problem.

Still another problem arises in the general area of display visibility which differs somewhat from the nighttime problems cited above. A considerable amount of data have been gathered and guidelines established concerning dial reading luminance levels, index mark spacing and the like. But, these data relate to painted surfaces, "iron gauges", needles, and pointers which have clean, sharp lines and other characteristics making them different from luminance emitting devices. We cannot be sure, without experimenting, about how much the existing data generalize to E/O displays. For example, E/O displays sometimes *jitter* and may appear to *blossom* but do not have parallax characteristics and do not require a wide ranging scan pattern, as do the discrete instruments. Kelso (1965) indicated a need for more research in this general area although her report concerns three specific scale factors. We concur with this need.

We also find a need for more research related to establishing the effects of varied CRT luminance intensity on contrast. More will be said about contrast later, but one point should be made clear concerning CRT low luminance levels. The contrast ratio of symbol to background does not of necessity remain constant throughout the range of intensities on raster type displays; nor is the relationship of contrast to intensity level linear. Therefore, it is not sufficient to establish a contrast ratio

at, say, 80 per cent of maximum brightness and expect that this will hold at the 1 per cent brightness level. Designers can minimize some of the contrast variability by using techniques such as gamma correction if they recognize a need for so doing. Selecting an appropriate night filter that acts as a neutral density medium can also help.

The preceding examples of recommended research are merely indicative of the types of studies that are needed prior to attempting a definitive statement of E/O display values which will be effective across a variety of operational conditions. We do not, for instance, have convincing data relating task loading, vibration, and fatigue to reaction time, symbol dynamics, display luminance, contrast, and color. We cannot specify the ways that such factors differ under dark adaptation rules as distinguished from less severe requirements. Similarly, we have insufficient data to clearly state how much resolution is required to detect a target on low light level television or on an infrared display. We have too little evidence to determine how a red night filter and a polarized or micromesh day filter plus some of the other variables mentioned above would affect the same resolution requirement.

It seems apparent that a meaningful specification must be written on the assumption that a systems approach will be taken and that certain system requirements will be known. Such system requirements can then be matched to appropriate display minimums. For example, a more rigid specification could apply to the case where dark adaptation is of fundamental concern; and a relaxed specification where it is not. However, uniform cockpit lighting might well apply to either case.

We are not suggesting that a different standard should be written for every conceivable variable. A standard might take the position that if such and such is a system requirement, then a display minimum characteristic of so and so is necessary. Perhaps the main point is that empirical research is needed to convincingly establish E/O display design minimums before they can be applied with authority to any condition. At this point some guides and approximate ranges of values can be stated. But, assumptions must be made about the applicability of these values to a given display problem. We recommend, therefore, that systematic studies be funded to relate appropriate E/O display characteristics to pilot visual needs in particular types of mission situations.

Until such data are available, the display designers will be forced to use subjective judgments of what such terms as *clearly visible*, *protect dark adaptation*, *adequate contrast*, *good human factors practices*, and so on, actually mean. The following introductory paragraph of the Smith and Goddard (1967) report illustrates the point quite well.

> *"The purpose of this report is to clarify an ambiguous situation resulting from paragraph 2.10.2 of the 1 October 1964 AFSCM 80-1, which states: 'Install integrally lighted instruments with a white lighting system designed according to MIL-L-27160. Use a red lighting system (MIL-L-25467) only if unique operator requirements dictate the use of red lighting and install only with the approval of the procuring activity.' Just what constitutes unique operator requirements is not identified in AFSCM 80-1. If the consideration is for dark adaptation requirements, it is hoped that this statement does not imply to the reader that the use of red lighting will preserve (that is, protect or save) the pilot's dark adaptation, and that white lighting will destroy it. This is not true; the differences are only relative. Even the pre-exposure to perceptually colorless light below cone threshold disrupts dark adaptation, and, obviously, pre-exposure to light above cone threshold would disrupt dark adaptation even more. Therefore, any notion that pre-exposing the eyes to red light will <u>preserve</u> dark adaptation is false."*

It seems that unless we are willing to invest some time and effort in generating what *protect dark adaptation* and similar terms mean in quantified language, our success in writing an E/O standard will be incomplete. The alternatives to establishing a program of definitive, systems oriented research are not difficult to imagine. For example, if we recognize a need to do something to improve cockpit lighting for preserving dark adaptation, our best approach, using only that information now available to us, would probably include at least the following:

1. Require that cockpits be uniformly illuminated with no source to exceed, for example, 1.0 ft L. Different values might be specified according to the anticipated mission requirement.

2. Require that certain symbol-to-background contrast minimums be preserved on the E/O displays.

3. Use best guess experience to establish ready procedures that minimize pre-exposure to adverse light intensity and colors.

Smith and Goddard (1967) provide a good summary of the red versus white lighting issue. They also provide an annotated bibliography of important research on dark adaptation. The following points are among those made in their report and summarize our thinking.

1. In those cases where mission requirements demand a maximum level of pilot dark adaptation, the use of red lighting for cockpit displays is recommended.

2. For missions requiring less stringent dark adaptation, the use of any color display illumination is acceptable.

3. In order to minimize the illuminated area, displays should be transilluminated when practicable. Caution must be exercised, however, in following such a guideline since extensive use of transilluminated displays may occasionally result in the pilot's loss of frame of reference for the panel, and the panel may appear to "float".

4. The current practice of light-on-dark display markings should be continued in order to reduce illuminated or reflecting display area.

5. Canopy glare, the reflection of light off of the canopy, should definitely be minimized.

6. Of the 10 variables affecting nighttime target detection (*e.g.*, target size, viewing time) only average pre-exposure luminance and pre-exposure lighting color are a function of cockpit instrument design and pilot behavior.

7. A systems approach to cockpit illumination should be made.

8. The available literature is inconclusive.

9. The pre-exposure tolerance of the pilot for a given aircraft mission should be considered.

<u>Day Vision</u>

We have just reviewed some of the complexities of night vision and its attendant red versus white cockpit lighting controversy. In this section even more complex problems are evident; although they are perhaps not quite as controversial.

Daytime ambient light conditions in the cockpit vary widely. Cockpit configurations range from those of the rotary wing type aircraft, which often have large transparent window areas, to those of the transport types, some of which have comparatively narrow windshield and window areas. The wide assortment of fighter and attack aircraft lie somewhere in between.

Such variety in windshield and window area tends to complicate the designer's problem in E/O display design. He must think about the particular cockpit for which his display is to be used in order to estimate the potential severity of glare effects, contrast washout, and moiré patterns caused by direct incident or reflected sunlight. In head-up display design, on the other hand, the main difficulty is that of generating adequate symbol intensity for viewing the projected display against a bright cloud or sky background.

The above problems are discussed in more detail under appropriate subheadings such as, Luminance and Contrast. For the present, we must address ourselves to the problem of establishing a criterion sky luminance condition.

A widely accepted *worst case* sky condition is 10,000 ft L. This represents the tops of white clouds at noon or bright sunlight on snow. Some reports disagree with this value, specifying from 8,000 ft L (Whiteside, 1965) to 12,000 ft L (Buddenhagen and Wolpin, 1961). However, 10,000 ft L is the figure deemed acceptable to most display designers.

Occasionally, a head-up display designer will mention a test criterion of "one or two diameters from the sun" as the basis for evaluating HUD symbol brightness. We do not recommend using this criterion for several reasons:

1. This method is too imprecise. Such factors as air density, altitude, sun angle, haze and disc *vs.* atmospheric halo must also be specified to make the definition precise. To include these variables in the definition would render it cumbersome and, ultimately, unworkable.

2. A clear reason does not exist for selecting one sun diameter as opposed to three, or thirteen, or even looking directly into the sun. One sun disc diameter is only about 0.5° (Sears, 1958; Air Navigation, 1963). Therefore, *one or two diameters from the sun* is tantamount to looking directly at the sun.

3. The percentage of time that a head-up display must be used within one diameter of the sun is, almost certainly, quite small. Such a criterion would result in an unnecessary overdesign. Clear sky brightness at moderate altitudes tends to be about 2000 ft L or less, although

> cloud reflections are often encountered, which may raise it by a factor of 2 or 3. (Pitts, 1963.)

We therefore advise using 10,000 ft L as the standard for maximum sky brightness for evaluating head-up display viewability. This represents the background against which a head-up display must be seen and the high luminance level for adaptation purposes.

The Cockpit and High Ambient Light

Our general concern in this section is to discuss the treatment of certain display characteristics and to relate these to the high ambient light environment to which E/O displays are subjected. To this end, some specific and practical matters are introduced which have a direct bearing on writing an E/O display standard. We will start by defining two useful terms from the field of photometry: *luminance* and *illuminance*.

Direct incident light falling on a display surface is specified as lumens per unit area and is called *illuminance*. An accepted unit of measurement is lumens per square foot, *foot-candles*. On the other hand, light reflected from or generated by a display may be specified in *foot-lamberts*, which is the measure of surface *luminance*. Luminance is often called brightness; although, technically speaking, the latter refers to perceived sensation rather than stimulus magnitude.

Both luminance and illuminance are important terms to incorporate into an E/O standard. These are particularly relevant when attempting to evaluate a head-down display which is being subjected to high ambient light. Without further qualification we can say that any attempt to specify the suitability of an E/O display for use in a high ambient light environment should at least contain the following:

1. A specification of minimum acceptable display contrast.

2. A specification of the intensity and direction of direct incident light falling on the display surface (*i.e.*, the protective filter) at the time contrast is measured.

Note that minimum symbol luminance is not mentioned above although it has some bearing on acceptable display contrast. The problem is that its relevance is only meaningful in terms of initial symbol luminance intensity, *i.e.*, prior to introducing the illuminant. Once high intensity illumination is added, as it must be to create the required high ambient environment, a minimum symbol luminance value looses its identity. At this point, only display contrast retention becomes meaningful. Some minimum symbol luminance intensity is, of course, necessary in order to provide adequate contrast in the presence of illuminating light. What

that level will be depends on such factors as the intensity and incident angle of the illuminating light, the characteristics of the display filter, and the reflectivity of the display phosphor. There is no point in speculating about a required minimum symbol luminance until some of the other values are known.

We might also add that any specification dealing with light measurement should include appropriate reference to photometric techniques. For example, frequency of calibration of the photometer and its known light source and such factors as the degree to which the photometer's wavelength response curve may depart from the photopic response of the standard observer's eye, should be included.

Our discussion thus far relates to the practical matters involved in evaluating a display's performance under demanding high ambient light conditions. Whatever minimum display values are specified, they should also be maintained in the presence of reflected light off the pilot's flying suit, white shirt, face, helmet, or visor.

Three questions arise in this regard.

1. What intensity of incident light (illuminance) should be specified?

2. How should the display developer or airframe prime contractor prove that his display meets the specified minimums under both day and night ambient light conditions?

3. What display luminance and contrast minimums should be specified?

The first two questions are actually parts of a single problem which is discussed below. The third will be deferred to the next section which deals with brightness and contrast.

We recommend that proof of a display's adequacy in day and night ambient light conditions be included in a human factors demonstration test, to be conducted by the display developer. We further recommend that the obligation be made contractually binding. The reasons for taking a firm stand on this matter are several. For example, it should be noted that maintainability and reliability tests are now an accepted part of overall program requirements. Human factors requirements are at least equally as important, but tend to be a bit more difficult to quantify and demonstrate. Our procedure would be a step in this direction. The human factors discipline is not likely to reach full maturity and contribute as it can and should to equipment design unless penalty-bound stature is provided. This, of course, implies responsibility as well as authority.

The above recommendation results from a genuine need to demonstrate equipment suitability and to resolve a chronic, although not necessarily an acute problem. Our recommendation is based not only on our own experience, but also on the concurrence of the many display developers, users, and research groups with whom we have talked.

Cockpit Lighting Mock-Up

Both the intensity of incident sunlight and the cockpit configuration of a particular aircraft should be considered in any demonstration test of the effects of incident or reflected light on display contrast. In order to control such variables, a rough cockpit mock-up is highly desirable. It would allow, for example, determination of the minimum angle of incidence at which sunlight is allowed to strike a given display and would provide an appropriate alternative to flight testing.

To understand why the above statements are made, the reader should consider for a moment the nature of head-down display mounting. Such displays, along with their protective filters, are usually mounted on a cockpit panel in front of the pilot or co-pilot. They may be afforded some protection from direct incident sunlight by a sun shield along the top of the panel, but are otherwise protected or exposed by the geometry of a particular cockpit configuration. The only certainty in any cockpit is that incident sunlight cannot reach a display through the pilot's body or the aircraft seat structure. At any rate, incident light striking a reflecting display surface will cause certain diffuse and specular glare effects. It will also tend to diminish display contrast. The severity of its effects relate to the intensity of the light, the angle of incidence that it describes, and the effectiveness of whatever filter or other technique is used to protect display contrast.

Such factors as the above are particularly important for evaluating the degree of protection afforded to a display by a directional filter. For example, a given micromesh filter may be designed to block most of the sunlight which would be incident to the display surface beyond a specified zone, *e.g.*, 15 degrees off-axis. If, however, direct incident light cannot in fact reach the display within 25 degrees of the normal axis (because of cockpit geometry) it would be unnecessary to determine washout effects within the zero to 25 degree region. Data of this type are deemed useful for estimating required CRT output in the planning stage of display design, as well as for proof of specification satisfaction later on. Such data should therefore be obtained.

While we are engaged in determining the effects of a particular cockpit's geometry on display contrast, other factors, such as the following, can readily be evaluated. For example, in establishing the intensity of incident light falling on a display surface we must consider canopy transmission and haze. Haze, in this context, refers to light scattering within the transparent materials (Wulfeck, *et al.*, 1958). The following

table from Glover (1955) outlines acceptable limits and shows how windshield angle of incidence affects transmission and haze.

TABLE 20 - LIGHT TRANSMISSION AND HAZE VALUES

		WINDSHIELDS INCIDENCE ANGLE				CANOPIES	VISORS
		55°	60°	65°	70°		
HIGHLY DESIRABLE VALUES	Transmission	71%	74%	83%	99%	89%	90%
	Haze	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
ACCEPTABLE IF OTHER FACTORS TAKE PRECEDENCE	Transmission	66%	69%	78%	93%	83%	86%
	Haze	1%	1%	1%	1%	1%	1%
MINIMUM VALUE	Transmission	64%	67%	75%	89%	77%	79%
MAXIMUM VALUE	Haze	2%	2%	2%	2%	2%	2%

(from Glover, 1955)

In considering the mock-up approach to display design, the following should be noted. There are some obvious reasons why it is rare to flight test a display prototype in order to establish suitability for a given cockpit application. For example, a new aircraft design requires that displays and the airframe be developed more or less concurrently. A flying model of a new aircraft is, therefore, probably not available for flight testing at the appropriate stage of display design. In addition, it is both expensive and inefficient to use an aircraft for some of the necessary tests in display design. For instance, conditions of light intensity and angle of incidence are difficult to measure and control in the aircraft environment. In order to overcome such difficulties, however, artificial lights can be used to simulate sunlight in an appropriate cockpit mock-up. By taking such an approach, the effects of canopy and windshield transmission losses, canopy haze, interior glare, bright surface reflections, and so on, can be evaluated.

Granting that a lighting mock-up is desirable for display evaluation, and that a demonstration test of display suitability is warranted, a high ambient illumination criterion must be established. In other words, what simulated sunlight intensity level should be used for display evaluation? The answer is somewhat arbitrary since a particular value will not cover all cases to everyone's satisfaction. However, the majority opinion is likely to agree with the following rationale.

One of the problems in determining a satisfactory intensity level for sunlight simulation is that sunlight intensity varies with altitude. For flights within the atmosphere, however, this factor is not believed to be significant.

The literature suggests that a meaningful specific intensity level is appropriate. For instance, Luxenberg and Bonness (1965) do not specify altitude but state that "a perfect diffuser in bright sunlight is illuminated by 9,000 foot-candles....". On the other hand, Gordon (in Duntley *et al.*, 1964) cites two reports on clear weather sky conditions at sea level. These establish sky illuminance at approximately 10,000 foot-candles when the sun is at zenith. These values seem to be typical, and we accept 10,000 ft C as a convenient approximation for our purposes.

As a final word, please note that the color temperature of the lamps used to generate simulated sunlight is not deemed critical for display evaluation. A broad spectrum white at about 5,000 to 6,500 degrees Kelvin is believed adequate. It should also be noted that ultraviolet and infrared light wavelengths serve no useful purpose for display evaluation and are generally to be avoided in illuminating light sources (Ketchel, 1967). Certain of the UV and IR wavelengths can be particularly harmful, given long exposures at high intensity levels, although they are outside of the visible spectrum. Xenon lamps in particular should be used with caution.

LUMINANCE AND CONTRAST

To date there has been a surprisingly small amount of research effort in the JANAIR and earlier ANIP programs aimed directly at establishing suitable display luminance and contrast for cockpit applications. One excellent report that does specify CRT luminance, contrast, and other characteristics is that submitted by Carel to JANAIR in 1965. We do not intend to duplicate his work in this section. Indeed, we suggest that readers of this report will find Carel's treatment of display characteristics most informative. Our purpose is to focus on display characteristics that are of particular interest to those charged with writing an E/O standard and to suggest areas of additional research when appropriate.

Luminance

Table 23 indicates that raster type displays are being designed using a nominal luminance of about 500 ft L. One may well ask what this implies in terms of actual requirements such as visibility or resistance to contrast washout. The ramifications of such a question are, unfortunately, based on many variables which manifest their effects according to such factors as the particular task a pilot must perform, the operating environment of the display, and kind of job that the display is designed for. The following are examples of variables that should be considered.

1. The most demanding acuity task that the pilot will encounter.
2. The degree of display contrast available under worst case ambient light conditions.
3. The transmissibility of whatever display filter(s) is used.
4. The number and interval spacing of whatever gray tones are required to perform critical tasks, such as terrain avoidance.
5. The transmissibility of the pilot's visor, cockpit glare factors, and the level of light adaptation of the pilot.

Our general view is that 500 ft L of CRT luminance should be quite sufficient for ordinary head-down display applications. If it is not, some measure other than increased display luminance is likely to be required. An even more challenging question, however, concerns the lowest acceptable symbol luminance level and the qualifications that might attach to such a value. Our subsequent development will be directed at this kind of problem.

To date, the one display that has been flown operationally, and therefore may be considered acceptable, is the ADI display in the A-6A aircraft. It yields a nominal 500 ft L luminance and provides 7 gray tones in the terrain avoidance mode. But, it does not follow that we should therefore accept 500 ft L as a standard luminance. There can be large gaps between

the acceptable and a more suitable or more optimal value. For one thing, experience indicates that a 500 ft L CRT output introduces heavy high voltage power supply (HVPS) demands under MIL-E-5400 environmental constraints (which apply to avionics equipment).

In addition to the HVPS problem, which has an important bearing on reliability, other factors must be weighed. For example, although 500 ft L is generated, a protective filter, such as the micromesh or a polarizing type, will reduce display output by perhaps 70 per cent as a result of filter transmission losses. The actual luminance displayed to the pilot in the above example would become 150 ft L, a value that is itself of questionable utility. For instance, a more efficient technique for preserving display contrast might easily permit such a value to be relaxed considerably; and, preserving adequate display contrast is, after all, the reason for generating relatively high display luminances. Such luminances tend to be more resistant to the effects of high ambient light washout.

Essentially then, the problem reduces to this: if we can assume that an adequate display contrast level will be preserved in the presence of high ambient light, we can directly address outselves to the important problem of specifying appropriate luminance for efficient and immediate task performance. The key prerequisite is a relative one. Do we want to preserve display contrast by brute force luminance or by developing more efficient contrast enhancement techniques? Penalties paid for the former seem to indicate that developing more efficient contrast enhancement techniques is our best approach.

Gray tone interval spacing is one of the more difficult problems in determining which display luminance characteristics are actually required. Carel (1965) shows that CRT output demands can be indeed great when contrast preservation of several evenly spaced gray tones is based primarily on display luminance. We would add, however, that more studies are needed in this area before conclusions about CRT requirements can be convincingly specified. Research may show that certain symbol luminance priorities can be assigned to critical symbols, or for example, the gray bands used for terrain avoidance, so that worst case high ambient conditions will not degrade critical performance tasks. To illustrate, it seems logical that a velocity vector symbol or a steering symbol would be far more important than ground texture elements and should be given contrast priority. The same is true of those terrain avoidance radar ranges which a pilot needs most for timely maneuvering. Our point is that there is no firm reason for assuming that an even spacing of gray tones is necessarily important or that equal contrast is required at each level. Instead, we should determine what the performance consequences of various gray tone schemes are and what better display contrast enhancement techniques are available. Then we can reach conclusions about the luminance requirements.

As a footnote to the above, it may conceivably be established that a line written head-down display affords essentially equal performance to that of a display which provides gray tone shading. We will not really know until two such displays are compared. The apparent disadvantages of line written displays are their inappropriateness for displaying LLLTV and terrain avoidance contour bands, an inability to generate the richness of a contact analog presentation, and limitations in symbol coding techniques. Such disadvantages are presumed to be more disabling for some missions and applications than for others. There is a definite need for comparative display analysis in this area.

In general, we believe that insufficient work has been done in the luminance and contrast areas. We cannot convincingly predict which symbol luminances, gray tone spacing, and filter characteristics are appropriate for given cockpit ambient environments. A recent study by Ketchel (1967), however, made an attempt to begin resolving some of these problems by investigating the effects of high intensity light adaptation on display luminance and contrast requirements. He found that a symbol luminance of 8 ft L is objectively necessary and about 17 ft L is subjectively comfortable for use in the presence of a 10,000 ft L adapting light "window". His stipulations are that a good contrast level must be maintained and symbol size must be suitably large (i.e., 15 to 23 minutes of arc or more).

The scope of the above study did not cover such variables as task loading, fatigue, and vibration. Of the variables that were investigated, however, it was found that the 8 ft L and 17 ft L minimum symbol luminance values hold regardless of whether or not the observer is wearing a sun visor. This point is important because it indicates the low range of symbol luminance which is acceptable, providing that adequate display contrast is maintained.

Ketchel concluded that wearing a visor which transmitted only 7.8 per cent of both the adapting light and display symbol luminance, effectively reduced the former without seriously degrading the latter. For instance, in his experiment the symbol luminance delivered to the pilot's eye through the visor for the 8 ft L symbol was a mere 0.6 ft L. But, in conjunction with the high symbol-to-background contrast used, 250 per cent, 0.6 ft L was adequate for immediate symbol detection and identification.

From all of the foregoing, it can be seen that luminance is difficult to discuss meaningfully without talking about contrast. Luxenberg and Bonness (1965) have this to say:

> *"Contrast, not brightness, is the significant factor in display legibility. Brightness is generally specified because it is dependent only on the equipment, whereas contrast is generally a function of ambient lighting. Brightness is also specified because it would seem that the higher the brightness*

the greater the visibility under high ambient light. This is not necessarily true, since some displays of lower intrinsic brightness have better visibility than far brighter ones."

The main idea in the above quote is well taken. Contrast is the most significant factor in display legibility. It was previously shown that a considerable amount of CRT luminance is blocked or sacrificed by a protective filter that is designed primarily for contrast retention. This suggests, as we indicated, that brute force techniques to increase display luminance are really attempts to achieve and maintain contrast under high ambient light conditions.

Subjective Magnitude and Stimulus Magnitude

A tangential point should be made in relation to increasing display luminance. Stevens (1962) makes a distinction between stimulus magnitude and psychological (*i.e.*, subjective) magnitude for various sense modalities. For example, a slight increase in the amount of electrical shock seems to the recipient as though the increase is manifold. However, to make the brightness sensation of 10 ft L appear to double, we must increase the luminance to 90 ft L, a factor of 9. Or, to put it another way, a display that produces 50 ft L does not seem to be half as bright as one that generates 100 ft L. Later, we will see that Clauer (1966) makes much the same kind of distinction in his discussion of contrast from the observer's viewpoint.

Although we consider the above information of importance for various purposes in display evaluation, we would add a comment. One should not assume, nor do Stevens or Clauer suggest, that performance on a given display necessarily equates with providing a duplicate psychological magnitude following, for example, the introduction of high ambient light degradation effects. Performance, in terms of speed or accuracy of response, relates to certain physical stimulus minimum values on the display. What these minimum intensity levels are perceived to be on a subjective basis is quite a different matter from how well one performs with them. Therefore, we need not strive to protect such display characteristics as gray scale rendition to the point of always having the display seem to have equal contrast under all ambient conditions. We should strive for good subjective picture quality but should accept display luminance and contrast values that provide adequate performance under test criterion conditions. More work is required to determine what some of the minimum acceptable performance values actually are.

Electroluminescent Display Luminance

When we consider electroluminescent (EL) displays it becomes quite apparent that great care must be exercised in the selection of a standard luminance

level. EL displays are comparitively weak in luminance; but this is not necessarily a deficiency, particularly in view of recent advances in EL contrast enhancement. (See Peterson, 1966, and Soxman and Hebert, 1968.) Thus, if we are not to set a standard which is prejudiced against EL displays, we should not select an arbitrarily high luminance minimum without qualification. Of course, a minimum suitable for CRTs need not be enforced against EL displays, just as head-up and head-down displays need not be judged together for minimum acceptable values.

The EL display issue calls forth a number of provocative questions about which there is some apparent difference of opinion; although the differences are believed to be more apparent than real. On one hand, we have such investigators as Peterson (1966), who suggest that EL displays are suitable for some cockpit applications. On the other hand, we have display developers who produce avionics displays having 500 ft L luminances and CRT developers who strive for still greater output levels. Are these factions contradictory?

Our interpretation of available evidence indicates that here, as in other instances, there is really no right and wrong dichotomy. Rather, there is a question of establishing what kind of job the display is supposed to do. To return to the questions asked earlier: Are terrain avoidance gray tones a requirement? What contrast enhancement techniques are available? How demanding is the high ambient light environment to which the display will be subjected? What resolution requirements are specified? Until such questions are answered judgment should be reserved as to which approach is or is not suitable.

Research Program

In summation, we are not convinced that brute force approaches to CRT luminance are the most appropriate means to solve the high ambient light problem. Nor is it abundantly clear that EL displays are suitable for doing all of those tasks now relegated to CRTs. We are convinced, however, that a sound evaluation and experimentation program would be very desirable for comparing these and other display generation techniques and formats in terms of pilot performance. The literature provides several examples of techniques that might be evaluated in such a program as that suggested. A sampling of these is given below, although a more detailed recommendation for a suggested program will be deferred until later.

1. Hughes Aircraft recently developed an experimental dark faced CRT for minimizing halation effects (Hoffman *et al.*, 1967). This technique deposits a dark layer between the phosphor and faceplate, thus providing a neutral density device and halation suppressor.

2. Lally (1966) suggests a non-linear optical filter that allows Stokes' Law principles to be used for contrast enhancement. He notes that most luminance materials absorb energy at some short wavelength and reemit it at some longer wavelength and that the process is not reversible. His approach is said to be similar to that of having an ideal black body display.

3. Micromesh filter design improvements have been suggested to improve transmissibility.

4. The use of photochromic materials in the cockpit canopy has hardly been explored; even though this might provide an excellent shield for some types of over-the-shoulder incident light problems.

5. Peterson (1966) and Soxman and Hebert (1968) report promising advances in EL display contrast enhancement.

6. The He-Ne laser has recently been suggested by Kilpatrick (1966) as a possible head-up display light source. Exceptional high brightness levels may be attainable using such a technique.

7. Bell Helicopter has developed a head-mounted CRT display that affords exceptional freedom of head movement as well as external field of view advantages.

8. Trichroic coatings for contrast enhancement of head-up displays has been given some evaluation and endorsement; but needs to be studied in more detail.

Examples of techniques, comparisons, and study issues that can and should be explored are plentiful. The above list is merely representative of some of the hardware related techniques that are known to be of immediate interest.

A systematic program of display evaluation,such as that suggested above, would allow us to chart the strengths and weaknesses of given approaches to display technique and format. Solutions to problems could be identified and related to given constraints on the basis of empirical evidence. In addition, performance criteria against which to evaluate subsequent display designs could be made available. We will summarize by noting that such a program could be used to test new techniques and concepts, evaluate controversial points of view, and establish a bedrock of data upon which to structure and update a standard. It is our conviction that a program of inter-display comparisons should precede or at least run concurrently with an in-depth concentration of resources devoted to any one particular display or concept.

Head-down Display Luminance Minimums

In view of the foregoing developments and qualifications, we find that insufficient research has been performed to allow us to specify convincingly a minimum acceptable display luminance value for head-down displays without reference to a specific application and environment. Even those data which are directly related to electronic display luminance (e.g., Ketchel, 1967) are more indicative than definitive.

If pressed to specify a minimum symbol luminance for head-down display guidance purposes, we would tentatively suggest that a symbol of adequate size which provides a luminance of 17 ft L after passing through a protective filter, and which affords a contrast of 250 per cent should be comfortable for use in ordinary applications.* On the other hand, a 10 ft L symbol luminance at 100 per cent contrast would be acceptable in terms of accuracy of identification and response time. These conclusions are based on Ketchel's study, the results of which he warns should not be generalized too far without supporting research. Note also that high ambient incident light will add to whatever symbol luminance is generated as a function of filter and phosphor reflectivity. We can only conjecture about what reflectivity and transmission values might be appropriate for a given application. Carel (1965) often uses the example of a filter that transmits only 10 per cent, but this is assumed to be merely illustrative and for explanatory purposes.

As a final word, we add that a suggested luminance or contrast level should not be forced on a display designer who can prove that his approach affords equal accuracy, response time latency, and approximate viewing ease. For whatever luminance minimums may be given, however, an acceptable measurement technique should also be described in detail. Such a statement should cover non-uniformity of CRT luminance, whether or not blanking is to be used, the raster size, and guidance on photometric calibration and techniques.

Head-up Display Luminance

We are not aware of any research that has been aimed at specifying the required luminance of a head-up raster type display. Nevertheless, such displays may be designed for TV weapon delivery in the near future. The need for appropriate research seems evident.

The situation is not a great deal better for head-up line written displays, although Kelley *et al.* (1965) do offer some empirical evidence as a starting point. They found that, against a 10,000 ft L background (sky) condition, 1,000 ft L of display luminance reflected from a clear combiner is quite marginal. Their experiment revealed that for the particular display system and combiner used, 90 per cent of the CRT luminance was lost through the combiner. This, of course, is not necessarily true for all head-up displays. Be that as it may, using an uncoated combiner in Kelley's experiment, it was estimated that perhaps 1800 to 3500 ft L of display

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* See pages 233 ff for a discussion of contrast.

luminance would be necessary at the pilot's eye for comfortable viewing.

When using a trichroic coating on the combiner, however, Kelley found that an equally comfortable display luminance was provided by delivering 800 to 1200 ft L to the pilot. This resulted although Kelley's trichroic sample was designed for a 55° angle of incidence and the display optical configuration required a 62° angle. In other words, the sample was not designed for efficient operation with the experimental display. As used in the experiment however, at a 62° angle, the trichroic sample reflected 25 per cent of the CRT luminance and transmitted 81 per cent of the simulated sky background light. The merits of a display enhancement technique such as the trichroic optical coating are not difficult to envision.

We will discuss trichroic coatings more fully in this chapter under Filters. But, before leaving the topic we can note that the experiment cited above was exploratory; it used a small sample size, a non-representative coating, and did not investigate the effects of wearing a pilot's visor.

We must conclude that more work is required before a firm recommendation can be made as to minimum acceptable trichroic coating or head-up display luminance characteristics. For example, trichroic transmission versus reflectivity tradeoffs must be evaluated to assure adequate night vision. We should also determine the effects of driving CRT phosphors at various high output levels. Pfahnl's (1961) report which deals with the latter, will be discussed later on. Unfortunately, it describes evaluative work at CRT intensity levels which are too low for extrapolation to the head-up display problem. The data are, however, indicative of the kind of studies that are needed.

An alternative possibility might be that suggested by Kilpatrick (1966). He reports that the He-Ne laser might be used as a high intensity light source for head-up display applications. At this time, we do not have enough data concerning the reliability of such devices for operation within a variety of cockpit environments. However, if comparative cost, ruggedization, and MIL-E-5400 requirements are not limiting, such a technique seems to be worth exploring.

Contrast

As mentioned previously, contrast and luminance are not easily separable. Several of the comments made in the preceding section on luminance are equally appropriate here.

Many of the existing recommendations on symbol size and contrast requirements in the presence of given ambient light intensities have resulted from Blackwell's (1946) work. His results are often referenced (McCormick, 1964; Hardy, 1963) and are evidently the basis for much of Carel's (1965)

comment on display contrast requirements.

Although the Blackwell work is an exceptional example of careful and extensive data collection, generalization from it for E/O display purposes should be done cautiously. Consider the following points:

1. Blackwell developed 50 per cent threshold data. This means that at the stipulated values of contrast, half of the subjects did not detect the presence of the stimulus at all. A rule of thumb multiplication factor of two is used to correct the given value to a 99 per cent probability of detection. But, nevertheless, the data refer to detection, not to recognition of the stimuli (Hillman, 1966).

2. Blackwell's data were gathered in the range 10^{-5} to 1,000 ft L (Hardy, 1963). The range 1,000 to 10,000 ft L was not investigated.

3. The subjects were all young women, aged 19 to 26, with 20/20 uncorrected vision.

4. The subjects were seated in an auditorium and had nearly ideal viewing conditions in terms of even light distribution and freedom from distraction. They were not wearing sun visors, did not experience vibration, had no instrument scan problem, did not have to search the display area to find the target, were not burdened with additional tasks, and were presumably not as strongly motivated (i.e., under equivalent stress) as a military pilot might be.

To allow for some of the obvious differences between laboratory data and practical applications, a field factor correction is applied. A factor of 15 is specified by Carel (1965). McCormick (1964) notes that a field factor of 15 refers to the general capacity of seeing moving objects under field conditions. McCormick cites Crouch (1958) as having developed Blackwell's data to obtain curves for field use.

The questions that arise from the above have to do with the validity of generalizing from Blackwell's data to the pilot's task regardless of whether or not a field factor is used. In lieu of specific research it is proper to use the best available data, such as Blackwell's. However, because there are so many variables that complicate the pilot's visual task, specific research designed to confirm or modify the Blackwell and Crouch findings for cockpit displays seems entirely reasonable.

A study by Hanes and Williams (1948) on radar visibility shows that at their highest adapting level, 2,000 millilamberts, a contrast ratio of 2.50 is required for immediate detection of a radar target on a PPI display (at a display luminance of 0.22 millilamberts). Ketchel (1967) used an identical contrast ratio but increased the adapting light levels to 10,000 or 5,000 ft L for subjects, both with and without a pilot's visor. In this study it was found that latency effects did not manifest themselves until symbol luminance was reduced to below 8 ft L. In other words, there was no time delay as a function of the high intensity adaptation level/display luminance mismatch until the display was reduced to below 8 ft L. Subjects could identify 8 ft L symbols as quickly as they could identify 30 or 100 ft L symbols of equal size (23 minutes of visual angle). The task was to search a direct view, raster display, which was sectioned into four areas, and to identify which of two symbols appeared.

Contrast Formula

A number of methods for specifying contrast are available and are used by various authors. Unfortunately, it isn't always clear which method is being used. Therefore, we recommend that one method be adopted by the standards committee, not as the only suitable method, but rather, in the interest of common understanding.

An often used formula for contrast is that which divides the difference between symbol and background luminance by the background luminance. The problem is that values for bright symbols against dark backgrounds range from zero to infinity. However, for dark symbols against a bright background, we must either deal with negative numbers or subtract the symbol intensity from the background. In this case, dividing by the background (which is a higher intensity) restricts the contrast range to between zero and plus one.

To avoid these difficulties we recommend that the following formula be used (see for example Graham *et al.*, 1965).

$$C = \frac{L_h - L_l}{L_l}$$

where: L_h = high luminance
L_l = lower luminance
C = contrast

Multiply by 100 to express C as a percentage.

Unless this or a similar formula is adopted, the direction of contrast should be noted for a clear understanding of what a given contrast means. That is, symbol-to-background or background-to-symbol contrast should be specified.

Subjective Contrast and the Modulation Transfer Function (MTF)

In discussing contrast from the observer's viewpoint, Clauer (1966) distinguishes between physical contrast and subjectively perceived contrast. This distinction is similar to that of Stevens (1962), who differentiates between stimulus intensity and psychological magnitudes of brightness.

Both Clauer and Stevens suggest that we cannot assume that the human visual response system acts like a measuring machine, which objectively records absolute increments of a physical stimulus at each point on a magnitude scale. A difference of one increment, for example, may seem to be a large or small change to the human visual mechanism according to the level on the scale at which the change is introduced. For high intensities of luminance or large percentages of contrast a small increment (or decrement) may not be noticed at all by the visual system. Nor will such a change be perceived below threshold levels. Clauer has this to say: "*...the human visual system, unlike the physical system, does not respond at all at contrast levels below the contrast threshold and, above this threshold,* (it) *respond*(s) *as a nonlinear function of modulation.*" Here, modulation can be taken to mean contrast.

As an example, Clauer asks whether an observer perceives a physical contrast change of 10 per cent at high contrast levels as equivalent to a 10 per cent change in contrast at low levels. He contends that such changes are not perceived as equivalent and illustrates his logic by using the graph in Figure 18.

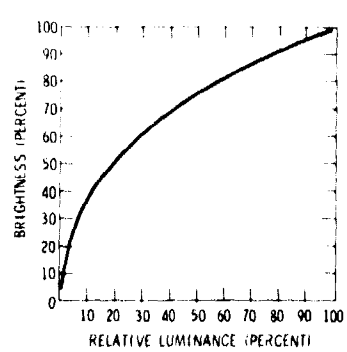


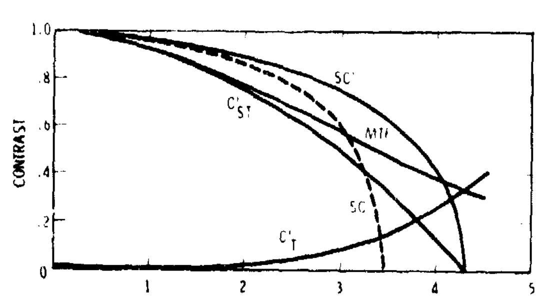
Figure 18 BRIGHTNESS AS A FUNCTION OF RELATIVE LUMINANCE (RENOTATED MUNSELL VALUE SCALE)

(Adapted from Clauer, 1966)

Figure 18 relates a linear scale of equally spaced Munsell values, which represent psychophysical color brightness, to a relative luminance scale (contrast) which is also equally spaced. It can be seen that a relative luminance reduction to 25 per cent is equivalent to a reduction on the Munsell scale to 50 per cent. It is also apparent that a 10 per cent change in contrast is perceived as being of a greater psychological magnitude at the low end of the curve.

A modulation transfer function (MTF) may be defined as the ratio of modulation of a reproduced image of a sine-wave target to the modulation of the original target. This concept is useful, as Carel (1965) suggests, for characterizing physical image systems. He notes, in a discussion of resolution, the MTF is normally plotted against spatial frequency or lines per unit length. For serial components, system MTF is found by multiplying the individual component MTFs.

Clauer, in his discussion of display contrast, agrees that the MTF is useful for describing system physical characteristics. He adds, however, that the MTF is not entirely suitable for providing quantitative evaluations of displays from the viewer's standpoint. This is, of course, related to his foregoing comments about subjective and physical contrast. He supports his position by showing that subjective contrast curves can be related to the MTF for different luminance levels (Fig. 19). In short, Clauer's goal is to find a convenient way to measure the system and its components, and also, to describe quantitatively what this means to the observer.



SC' = Subjective Contrast

SC = Subjective Contrast at 20 ft L (for comparison)

C'_T = Contrast Threshold

MTF = Modulation Transfer Function

C'_{ST} = Suprathreshold Modulation curve (obtained by subtracting the C'_T curve from the MTF curve)

Figure 19 GRAPHIC CONSTRUCTION OF SUBJECTIVE CONTRAST AT 300 FT L.

(Adapted from Clauer, 1966)

We believe that Clauer's approach has merit and should be evaluated fully in connection with E/O displays. The notion that subjectively perceived contrast is more important than physical contrast (*i.e.*, the objectively measured difference in stimulus magnitudes) may be of considerable value in determining the proper spacing of gray tones for displays which use this as a coding dimension. The fidelity of the MTF and corresponding subjective contrast may also serve as a useful way of evaluating displays which present televised displays of the real world for the purposes of weapon delivery, reconnaissance, or low level contact flight at night.

Shades of Gray

The presentation of shades of gray on a raster display is one of the more vexing problems of display design. It has been touched upon in Chapter IV in connection with coding dimensions and earlier in this chapter in the discussions of luminance and contrast. The problem centers about two questions. How many gray tones are needed or usable? What should be the range of the gray tone scale and the spacing of intervals within it? Unfortunately, the answers to these questions are elusive and, if found, subject to qualification.

For the direct view raster displays analyzed in this study, seven to ten shades of gray are specified. Although no display actually makes use of the full ten-shade gray scale, this figure seems representative of what designers and users believe and manufacturers accept as a suitable maximum for displays which use shading as a coding dimension. On the other hand, work by Miller (1966) and Alluisi and his colleagues (1957) indicates that, insofar as shading is a coding dimension, six or seven shades of gray is the maximum usable number. More recently, Slocum, *et al.* (1967) also suggest seven as a practical number of gray scale steps, although they do not indicate the empirical grounds for their opinion.

The difference between seven and ten is not as trivial as it may seem. If we assume a 100 per cent contrast between adjacent shades of gray and a value of 4 ft L for the lowest shade of the scale, a seven shades of gray display requires a luminance of 256 ft L for the lightest shade. A ten shades of gray display would require over 2000 ft L for the lightest shade. That is, a ten step scale requires a maximum display luminance which is eight times more than a seven step scale. Clearly, the range of the scale and the number of steps makes an enormous difference in terms of hardware design and reliability since, generally, the higher the level at which the CRT is driven the shorter the tube life.

The foregoing example is admittedly simple. Many other factors must be considered, but most of them tend to indicate that even higher maximum brightness levels would be required. The earlier discussion of the modulation transfer function indicates that, at the higher luminance levels, greater than 100 per cent contrast might be required between adjacent

shades of gray. The use of protective filters reduces overall display luminance and, therefore, might require a generally higher luminance level to insure that the display will be usable in high ambient light conditions. The contrast ratio of 100 per cent in the above examples was chosen somewhat arbitrarily. Some research findings (*e.g.*, Hanes and Williams, 1948) suggest that - for radar displays, at least - an even higher contrast ratio is called for, perhaps as much as 250 per cent. A study by Ketchel (1967) indicates that factors such as symbol size, adaptation level, symbol luminance, and the use of a sun visor may combine to produce a situation in which 100 per cent and, at times, 250 per cent contrast is not adequate. In fairness, it must be pointed out that 100 per cent contrast may be too high. A study by General Electric (1961) states that 85 per cent is adequate for *most* visual tasks (our italics). In short, adequate gray scale contrast varies greatly depending upon the viewing conditions and the observer's visual task.

In practice, the shades of gray problem usually comes up in connection with one of three types of displays: a VSD with stylized symbols, a terrain avoidance display which uses shade coding for range, or televised displays such as LLLTV or certain TV missiles. A closer look at each of these applications may serve to clarify the problem and to suggest practical methods of resolving it.

For VSD symbols six or seven shades of gray are normally used although, as noted above, it is not unusual to find as many as ten called for in specifications. The problem here is not how many shades but, rather, how to provide adequate contrast between symbols and background to insure symbol legibility and to avoid washout effects in high ambient light conditions. It is possible to achieve this through judicious selection of shades for each symbol or class of symbols. For example, critical symbols such as a steering symbol, impact point, or command altitude index should be brightest and have the best contrast with the general display background. Since these symbols are normally viewed against an artificial sky and ground plane, the latter display elements should be dark, *i.e.*, at least two or three gray tones darker than the critical symbols. Less important display elements, such as ground texture which is used primarily to enrich the background or to provide qualitative contact analog cues, need not have such high contrast.

In most cases, it is fairly easy to decide which symbols are of greater or lesser importance and to assign gray scale values accordingly.

In some circumstances, however, it may not be possible to control the background against which the symbol will be viewed. That is, the symbol may be free to range over the entire display and thus be presented against several different gray tones. A common solution, here, is to have the symbol carry its own high contrast background with it, *i.e.*, to enclose the symbol with a border whose shade is several gray scale intervals removed from that of the symbol. This technique is often used with alphnumerics, which are presented as a bright figure inside a dark box. By this method

it is possible to obtain symbol/ground contrast on the order of several hundred or even thousand per cent.

Some terrain avoidance displays employ a quasi-VSD format in which terrain contours are presented in azimuth and elevations and the range to these terrain contours is coded by gray tones. The terrain avoidance display of the A-6A ADI is of this type and will serve as an instructive example. The A-6A ADI is capable of presenting ten distinct shades of gray. These are used to represent ranges from 1/4 to 10 miles ahead of the aircraft, with the range intervals becoming larger as the range to terrain increases. Through simulation and flight test it was discovered that only about 5 or 6 of these ranges (and, hence gray tones) were of use to the pilot, who tended to concentrate on the terrain closest to the aircraft and disregard range information beyond 3 to 5 miles ahead. In this case, it was possible to reduce the number of gray tones and widen the interval between them thereby achieving a better match between information content and symbology, increasing the contrast between adjacent shades of gray, and relaxing hardware requirements. The point, here, is that analytically derived requirements must be verified through simulation and flight testing of prototype equipment. The variables studied should include the number of gray shades, the amount of contrast, the number of intervals to be encoded, and dynamic effects such as speed, altitude, vibration and wind gusts.

For televised presentations such as LLLTV or missile TV, the problem is to achieve a realistic or at least readily interpretable rendition of a real world scene. This is one of the most demanding tasks yet required of E/O displays and sensor systems. In part, it is a problem of resolution, which is discussed elsewhere. However, the resolution problem is complicated by present sensor-display system limitations and, in the case of LLLTV particularly, by the inherently poor visual quality of the real world scene under low light conditions. In terms of gray scale rendition, the problem manifests itself in a need for a relatively large number of distinct gray tones (*i.e.* 10 or more) in order to compensate for sensor inadequacies.

Something on the order of ten shades of gray appear to be needed for the presentation of realistic TV images, at least insofar as commercial television is concerned. However, it is by no means certain that commercial quality television is adequate for the specialized purposes of weapon delivery or night reconnaissance. The required number of gray shades and the minimum acceptable contrast between them have not yet been adequately fixed by research. Perhaps a wide latitude exists in terms of gray shades if resolution requirements are suitably handled. The interaction effects of these variables are not certain. Research should also include a more penetrating analysis of existing literature pertaining to TV detection ranges and experimental testing of various combinations of imaging chain components.

FILTERS

One of the most serious problems with direct view displays is protecting them from washout (loss of contrast) in high ambient light. There are several techniques and devices which have been found helpful for this purpose. The two most widely used are the micromesh filter and the circular polarized filter. However, before examining these, let us glance at some of the other techniques for improving display visibility and comment briefly on their suitability and limitations.

1. Neutral density filters - These are transparent devices that reduce the intensity of light transmission without changing the color of that light. Used as protective devices, neutral density filters reduce display luminance as a function of their density, *i.e.*, the percentage of light that they are designed to transmit. Incident ambient light, however, is reduced both on its way to the display surface and again as it reflects back from that surface.

   As separate devices, neutral density filters are not generally used for displays because they are relatively inefficient. But, it should be noted that neutral density effects are provided by any density agent interposed between the viewer and the display. For example, blackening on the inside surface of a CRT, for suppressing halation, creates a neutral density effect. The micromesh filter, in addition to blocking light at certain incident angles, also acts as a neutral density medium.

2. Direct view storage tubes - This is a brute force method of increasing tube brightness to levels which are high but still somewhat below that attainable with conventional CRTs. Pizzicara (1966) advises that brightness levels of 200 to 4000 ft L are typical for direct view storage tube operation. He also notes that a conventional 5-inch CRT costs about $50, while a direct view storage tube can cost $1,000 or more. Aside from cost, these tubes tend to be more complex, to present problems in matching persistence to display up-date requirements, and to have marginal resolution and gray scale rendition.

3. High brightness CRTs - Carel (1965) points out that the high brightness direct view CRT has been the generally preferred approach throughout the years. He is optimistic about the development of an 8-inch diameter direct view CRT operating at 30KV, giving 1000 line resolution, and with highlight brightnesses in the 20,000 ft L region.

   At the present state of technology, high brightness CRTs pose serious questions of cost and reliability. There is also a point of diminishing return at which higher voltage will not yield a proportional increase in brightness. Further, with present phosphors the danger of phosphor burn increases with higher voltage beam currents.

Equally important, experience with operational avionics displays using conventional CRTs with 15KV power supplies has shown that the stringent environmental testing requirements of MIL-E-5400 are difficult to meet. One can easily envisage how much greater the problems would be in producing, at a reasonable cost, a reliable high brightness CRT display system which offers significantly greater brightness and resolution than present displays, especially when this may require a substantial increase in the high voltage power level.

4. Non-reflecting phosphor - For both EL and CRT displays the preservation of contrast by using non-reflecting phosphor is believed to be an effective technique.

   The non-reflecting phosphor approach to EL displays seems to be especially promising since EL luminance intensity is characteristically low. Other filtering methods, which may block 70 per cent or more of disp' luminance, would be a serious handicap in EL displays.

5. Non-linear optical filters - This technique makes use of Stokes Law to exploit the characteristic of irreversible wavelength shifts common to luminescent materials (Lally, 1966). The technique is also called the diode effect. Without going into detail, the principle of Stokes' Law is that luminescent materials absorb energy at some short wavelength and re-emit it at a longer wavelength. By using the proper filters, Lally proposes to block and absorb most broad spectrum ambient light before it can reach a reflecting surface. The display generated short wavelength light, however, passes through a long wavelength blocking filter, is then converted to a longer wavelength by a fluorescent layer, and finally exits through a short wavelength blocking filter.

   Although this technique seems promising, it has not, to our knowledge, been thoroughly compared to other techniques or evaluated in high ambient light environments. We are, therefore, not able to discuss the limitations which may become manifest.

6. Fiber optic faceplates - These are considered effective but are excessively costly for large displays.

   In this technique, thousands of tiny light transmitting fibers are cut to a specified length, are bonded together, and are packaged into a honeycomb configuration similar to that of the micromesh filter. Advantages of this filter technique are that transmission is relatively high for display generated light and multiple laminated layers are not needed (as they are in micromesh filter designs).

   One of the manufacturing difficulties associated with fiber optic

faceplates is that in order to make large filters (*e.g.*, 5 inches by 7 inches) at a reasonable cost with available equipment, small component sections (*i.e.*, smaller filters) would have to be bonded together. This presumably would cause visible lines to appear between adjacent component sections. Whether or not such lines would be noticed by a pilot or degrade his performance is not known, nor is it known whether manufacturing techniques and equipment could be devised to allay some of the problems.

7. Photochromic materials - The Corning Glass Company has developed a process whereby transparent materials can be made to darken upon exposure to light. The process is completely reversible, but the restoration to full transparency usually takes longer than the initial darkening. Glass or plastic is impregnated with silver halide compositions (Justice and Leibold, 1965), or some other chemicals which darken upon exposure to certain wavelengths of light. Temperature also affects the process in terms of the speed of response, thus providing a secondary means of control.

   This approach to the cockpit high ambient problem has hardly been explored although it shows promise. Certain aft sections of a canopy might be darkened automatically and/or be placed under pilot control to reduce over-the-shoulder direct incident light on critical display panel areas. The process also has application possibilities for atomic flash protection.

The above list is not intended to be a complete summary. It merely highlights some of the more promising or better known techniques for display protection in high ambient light. The two most popular techniques, the micromesh and circular polarized filters, are discussed in greater detail below.

Micromesh Filters

This type is sometimes called a honeycomb, grid, or directional filter. It is made up of finely perforated metal plates laminated between layers of glass. The filter thus consists of thousands of tiny transparent cells or holes. Incident light striking the filter parallel, or nearly parallel, to the axis of these holes is passed; light striking at more oblique angles of incidence is blocked. The incident angle at which light is passed, called the cone of acceptance, is determined by the diameter of the holes and their depth. Usually the cone of acceptance is on the order of ±15° from normal. Since the blocking effect operates in both directions, *i.e.*, for light emerging from the display as well as for ambient light, the filter creates a cone, in which the observer must keep his head, in order to view the display. While it might be expected that this would limit the range of observer head movement, in practice this does not usually prove to be a serious restriction since a 30° cone (±15° from normal) offers considerable freedom of movement (±7 inches or so) at the customary 28 inch viewing distance.

A more significant practical consequence is that the use of a micromesh filter prevents side-by-side observers from sharing a single display. There seems to be no simple solution to this problem since opening up the acceptance angle of the filter to a point where both observers can see the display also renders the display vulnerable to ambient light and washout effects. The problem can most easily be resolved by providing a display for each observer or by using some other type of filter.

Of more importance is the fact that display luminance is considerably reduced by the neutral density effect of the filter, only 25 to 30 per cent of the available display luminance being transmitted. The majority is sacrificed to preserve contrast. Better transmission might be achieved by improved design and manufacturing techniques, but such speculation is beyond the scope of this discussion. We suspect that transmission could be improved without degrading efficiency if sufficient effort were directed to this end.

It is said that the micromesh filter produces a slight reduction in resolution. While this may be true, we have seen no evidence that this is of practical significance for the majority of display applications. Any significant loss of resolution would presumably be for a display which required extremely fine reading or for a system with unusually high resolution characteristics. Neither circumstance is true for the ordinary VSD.

Micromesh filters, and for that matter any other cockpit glass or transparent plastic surface, should have antireflectance coatings on each reflecting surface to reduce specular glare. It should be noted that such coatings block visible wavelengths of light, but not necessarily infrared or ultraviolet. The canopy may block much of the shorter UV wavelengths, but it has comparatively little effect on IR, and the pilot - theoretically - can be subjected to some impressive doses of IR without knowing it. Unfortunately, the most serious consequences of overexposure to IR are irreversible. Such damage may result either from exposure to very high intensity levels or more moderate intensities over long periods of time. Retinal burn and partial blindness can result without the victim being aware of it since the retina contains no pain sensing nerves. We have seen no reports of pilot difficulties in this area, and the problem may be of no practical consequence for most aircraft. However, as the operating altitude of aircraft increases and the attenuating effects of the atmosphere lessen, the danger becomes more real.

Circular Polarized Filters

The following descriptive and illustrative data are provided by the Polaroid Corporation.

Circular polarization makes use of a linearly polarizing filter plus a quarter-wave retardation sheet, which has its axis oriented at 45° to the transmission direction of the linear polarity. This configuration "twists"

the light so that vibrations leaving the retardation filter form a helix of right or left circularity in two axes, slow and fast. The effect is to create a retarded beam one quarter out-of-phase with that of the other axis.

When a circularly polarized light ray reflects from a specular surface, a reversal in helical rotation occurs. On re-entry through the quarter wave component, the change in direction and rotation results in an additional quarter wave shift. The total phase shift results in transforming the reflected circular polarity into linear exit polarity, oriented 90° from that created initially. Since the linear polarizing filter will not transmit light 90° off axis, it blocks the reflected ambient but permits display generated light to pass.

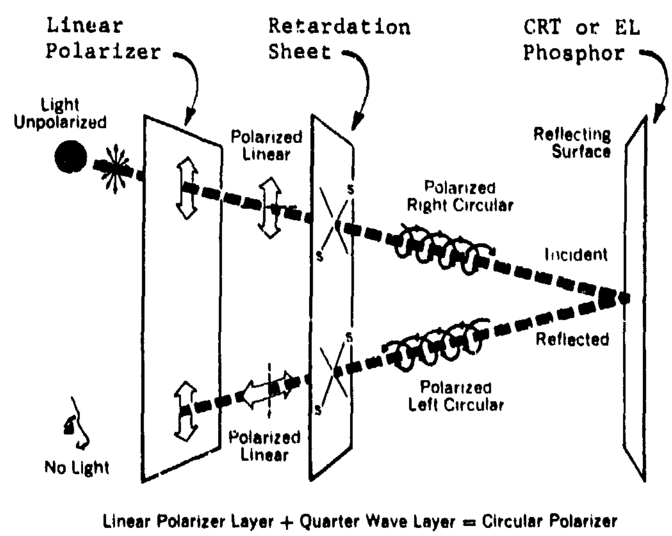


Figure 20 A CIRCULAR POLARIZER

A circular polarizer is a "sandwich" consisting of a piece of linear polarizer bonded to a quarter-wave retardation sheet oriented at an angle of 45° to the transmission direction of the polarizer. This schematic diagram shows what happens as light passes through.

(Adapted through courtesy of The Polaroid Corporation)

The blocking effect is most pronounced when the reflecting surface emits specular reflections. Because phosphors tend to emit both specular and non-specular (depolarizing) reflections, the amount of ambient washout protection varies as a function of this factor.

The physical properties of Polaroid Corporation plastic and glass laminated polarizers restrict applications to a temperature range of -76°F (-60°C) to + 175°F (+ 80° C) with short permissible exposures to 200°F. Stability is not guaranteed at operating temperatures above 175°F. Polarizers are also affected by a combination of high relative humidity and temperature. Polarization diminishes with time of exposure to high intensity UV radiation. The effects of IR and X-rays are not specified.

Comparative data seem to indicate that polarizers are not superior to micromesh or neutral filter devices unless specular reflections are of significant importance. In so far as this report is concerned, *i.e.*, for anticipated E/O display standards, compelling reasons cannot be identified to qualify one protective device over another. The matter should be left to the discretion of the display designer, air frame manufacturer, or buyer. A fiat from a standards group is not warranted in this instance.

<u>Trichroic Color Separation Filters</u>

As indicated earlier in this chapter, CRT luminance requirements can be considerably relaxed by using trichroic coatings on head-up display combiners (Kelley *et al.*, 1965). Such an application has been flight tested and approved for the F-111B head-up display. Test pilots reported that they could track an ordinary star across the windshield and combiner without noticing a pronounced loss of brightness when viewing the star through the combiner. They concluded, on subjective evidence, that night vision was not seriously degraded by the coating being flight tested.

A trichroic coating is a thin film deposit which reflects a narrow wavelength band of energy (*e.g.*, 50 millimicrons wide) while transmitting most of the energy at both longer and shorter wavelengths.

When the filtered notch is designed to remove the specific wavelengths of light which match the display phosphor color, *e.g.*, P 31 green centered at about 525-millimicrons, the contrast enhancement of the display is quite pronounced. The following describes what occurs:

1. Only a specific, narrowly defined, real world green color band is blocked. The world still looks green because other green wavelengths pass through the combiner.

2. The display color which is projected against the combiner from the interior side is reflected back to the pilot in strength. It seems all the more vivid because little matching real world green is present to degrade it.

3. The transmission of other wavelengths of light is not considered to be seriously degraded. Transmission for these wavelengths is on the order of 70 per cent. Pilots can, of course, look around the combiner if they so desire, but a need to do so is not anticipated.

Available evidence indicates that trichroic coatings are both appropriate and desirable for head-up display contrast enhancement. They are said to meet MIL-F-675 environmental test requirements.

CRT Reliability, Tube Life and Phosphor Burn

Hubner and Blose (1966) emphasize the importance of avionics display reliability in their report on F-111B flight evaluations of the V/HUD displays. We support their view and would advise against any brute force or other such technique that seriously degrades reliability. Wherever appropriate the trend should be toward reducing power, weight, cost, and complexity and enhancing reliability.

As noted above, Kelley's report indicates that trichroic coatings might well be used to relax CRT output demands. The problem is that we are not yet able to assign weights to the various factors involved, or to identify critical elements related to them.

Pfahnl (196.) discusses the aging of phosphors and shows that aging data can be represented to a first approximation by:

$$I = I_0(1 + CN)^{-1}$$

where: I_0 = initial intensity
I = aged intensity
C = burn parameter, cm^2
N = number of electrons deposited per cm^2

Three plots are shown in the report to illustrate the applicability of the expression $I = I_0(1 + CN)^{-1}$ to represent phosphor aging curves. Two versions of P 4 phosphor and one P 15 curve indicate that a straight line linear relationship is produced for some phosphors by the indicated expression. In these examples the ordinate is $(I_0/I)-1$; the abscissa is coulombs/cm^2.

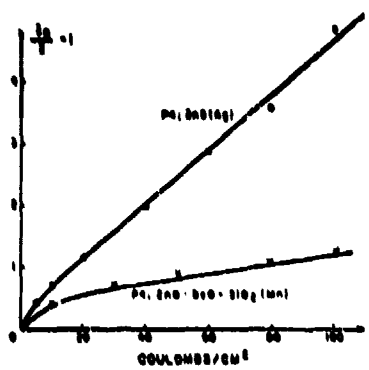


Figure 21 EXAMPLES OF DEVIATIONS FROM THE LAW $I = I_0(1 + CN)^{-1}$

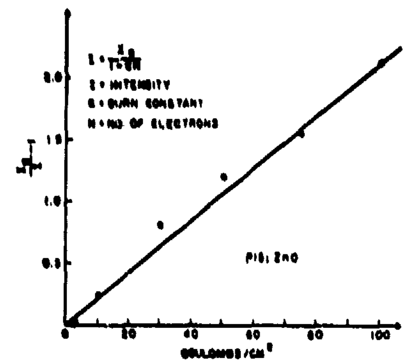


Figure 22 APPLICABILITY OF THE EXPRESSION $I = I_0(1 + CN)^{-1}$ to REPRESENT PHOSPHOR AGING CURVES

(From Pfahnl, 1961 by permission of Pergamon Press.)

Pfahnl notes that the burn parameter C as defined by the equation is a measure of the rate of destruction of the luminescence. He defines 1/C as the number of electrons necessary to reduce the intensity of the luminescence to one-half of its initial value. Table I of the Pfahnl report indicates that 1/C (expressed in Table I as the number of coulombs/cm^2 necessary to reduce I to 1/2 I_0) is 104.0 for P 1 type phosphor (10KV excitation), a value much higher than shown for the other phosphors represented. Unfortunately, P 20 and P 31 data are not given.

These data verify the suitability of P 1 phosphor for head-up display and other high intensity applications. But, even more interesting is the absence of sharp inflections in the curves. However, these plots do not extend beyond 100 coulombs/cm^2, and we are not apprised of their shape at higher levels.

Pfahnl has this to say:

> *"The exact mechanism of aging is, in most of the cases, not well understood. It must be investigated separately for each material. Conclusions can be inferred only from the results of several different types of measurements made before and after irradiation, such as light emission efficiency, thermoluminescence, dielectric constant, conductivity, etc. The mechanism of the aging processes for typical groups of phosphors is, nevertheless, qualitatively explainable."*

Although we do not purport to be expert in this area, the evidence seems to indicate, and Pfahnl agrees, that investigations along the lines of his report would be fruitful for higher intensity levels. More specifically, assuming that a more penetrating search of the literature does not reveal the required information, a study should be funded to determine the shape of aging and burn degradation curves for those phosphors likely to be used in avionics displays, particularly the head-up displays. At least the green phosphors, P 1, P 20, and P 31, should be evaluated. The objective would be to determine the relationship of tube operating level to phosphor burn and tube life degradation. If the relationship is sharply curvilinear for a given CRT phosphor at some intensity level, an effort could be made by the display developer to design controls that are helpful in keeping tube output below identified sharp inflection points. Such data would be useful in selecting the proper combiner coating after the desired CRT output had been established. Thus, an intelligent tradeoff could be effected to provide adequate day and night vision. If the curves do not exhibit sharp bends, the information would still be useful in estimating half-life degradation, failure rates, and so on.

Electroluminescence

One of the most important psychophysical factors in the E/O display field is determining adequate display brightness and contrast under a variety of ambient light conditions. A display that cannot be seen is useless. The problem is of particular interest to those concerned with the feasibility of solid state displays.

In discussing the intensity and effective life of EL phosphors, Peterson (1966) advises that EL phosphor improvement is not a promising means to achieve acceptable display readability under daylight ambient intensities. He concluded from a study in visual perception (presumably done at the Air Force Flight Dynamics Laboratory, WPAFB) that low emission displays can be seen in daylight ambients if they have acceptable contrast.

Peterson reports that, for a pilot adapted to 3,000 to 5,000 ft L, only 3 to 5 ft L of emitted light against a dark background is necessary to produce a usable display. Using high contrast filter techniques (the *"hi-con"* display), a mere 1.3 ft L afforded immediate accurate viewing of a simple numeric readout. This compares to a requirement of 36 ft L for an unfiltered EL display. Subjects in the above study were adapted to 5,000 ft L for 30 seconds, and the displays were flooded with 1400 ft candles of incident light.

Peterson does not specify required EL display contrast and brightness under the 10,000 ft C of incident light which we proposed earlier as a standard for evaluating cockpit display visibility. It would be most valuable to determine such data in controlled experiments. Peterson's

subjects were merely required to read a series of numbers generated on an EL panel. Stroke width, visual angle, fatigue, vibration, and similar variables were not systemmatically studied.

The report cited earlier (Ketchel, 1967) concerned a raster CRT display, but it generally supports Peterson's findings. To summarize briefly, Ketchel's subjects were exposed to either 5,000 or 10,000 ft L of adapting light and were required to identify a 23 minute symbol. Independent variables included: wearing a pilot's visor, display clutter, and, in some cases, a symbol size reduced to 15 by 5 minutes.

It was found that surprisingly low symbol luminance intensities and low symbol to background contrast ratios can be tolerated under laboratory conditions without introducing reaction time latency effects. Such practical considerations as task loading, vibration, and fatigue were not studied.

Following the Hanes and Williams (1948) work on radar display visibility, Ketchel used both a fixed contrast ratio of 2.50 and varied lower contrast levels. He generally concludes that the adaptation problem is not as formidable as are the washout effects from direct incident light. Merely wearing a 90 per cent blocking visor effectively minimizes the adaptation problem and yet permits comparably reduced symbol intensities to be seen across the range of values examined.

A recent report by Soxman and Hebert (1968) describes a high contrast, solid state display which makes use of a vacuum deposited EL thin film that is essentially transparent to ambient light. This permits a dark field structure to be generated for contrast enhancement. While testing of this display is still in process, preliminary results indicate that display readability can be maintained for a few thousand hours under ambient lighting conditions of several hundred foot-candles and perhaps more, even though the luminance output of the device is in the 1-10 ft L range.

Although it is perhaps too early to predict that solid state devices will replace CRT's for certain head-down displays, such conjecture is not entirely unwarranted. Adequate luminance intensity, resolution, and packaging have traditionally been the shortcomings of EL displays, but the reports cited above suggest that these are being overcome. In terms of weight, power requirements, space, replacement cost, and reliability the EL display may offer some advantages over the CRT. All these, however, are matters of technology and hardware, which are not in our purview. Our concern is with the readability of such devices when used as aircraft displays. It would seem that EL displays offer promise and that development is proceeding rapidly in this area. It also seems that those concerned with standardization should retain an open mind on EL display luminance and contrast until more research data are available. In this regard, it would be interesting and helpful to have data on pilot performance using a conventional VSD raster display in comparison with performance using a similar display of the EL type.

FLICKER

Critical fusion frequency (CFF) can be defined as the rate of change in the luminance intensity of a visual stimulus at which perceived flicker extinguishes and a smooth fusion occurs. The rate changes as a function of at least these variables:

- increased absolute brightness,
- the age of the subject,
- the difference between brightness levels of bright and dark stimulation phases (*i.e.*, the size of the increment),
- certain changes in the on/off duration ratio (*e.g.*, phosphor persistence changes),
- wavelength of light,
- size and location o the retinal area stimulated.

CRT's tend to create flicker because the raster and images are written and rewritten by a moving spot of light, thus creating bright/dark cycles. The electron gun must rewrite (*i.e.*, refresh) the image at a specific minimum rate, given certain existing conditions of luminance, to provide a picture perceived as fused or flicker free.

Poole (1966) states that early commercial TV testing led to the adoption of 60 fields per second at luminances up to 180 ft L for flicker free perception. He also advises that lower frequencies may be acceptable for some applications as a compromise. However, displays whose refresh rate is under 20 cps are said to be extremely annoying.

Other authors have diverse opinions about the shape of the CFF curve at high frequencies and luminance intensity levels. Morgan (1965) notes that the CFF varies from 2 or 3 cycles per second at very low intensities to about 60 cycles per second at high intensities. See Figure 23.

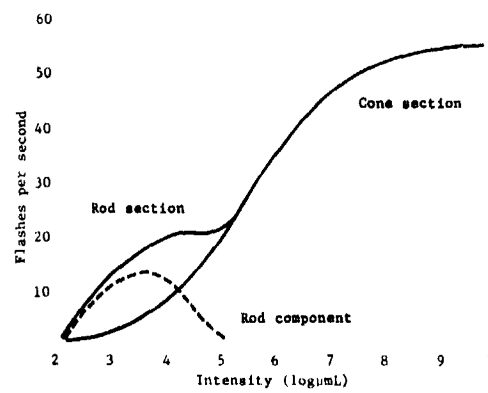


Figure 23 ANALYSIS OF THE CURVE FOR FLICKER DISCRIMINATION

(Adapted from W.J. Crozier and E. Wolf. Theory and measurement of visual mechanisms. IV. Critical intensities for visual flicker, monocular and binocular. *J. gen. Physiol.*, 1941, 24, 505-534. By permission of The Rockefeller Institute Press.) Cited in Morgan (1965).

Underwood (1966) cites data from Lloyd (1952) and notes a regular increase in CFF up to about 45 cycles per second.

Foveal stimulation levels off at this point while peripheral stimulation begins to reach asymptote at approximately 50 cycles per second for a stimulus subtending 2 degrees of visual angle.

Graham *et al.*, (1965) points out that visual summation effects occur over areas in the periphery than in the central retina and thus alter the relation of CFF to retinal locus for different test field sizes. For a small test field, *e.g.*, 12 minutes, CFF decreases over a wide range of luminances as the stimulus moves away from the fovea. But, for larger test field areas CFF may be higher in the periphery than in the fovea, even at relatively high luminances. The physiological reasons for these effects are not entirely understood.

Carel (1965) reproduced some CFF curves from Schade (1948) who showed the flicker threshold to be dependent on the ratio of viewing distance to screen diameter (*i.e.*, the visual angle subtended by the display), the field rate, and phosphor decay characteristics. Carel notes that although

Schade's curves imply that CFF keeps increasing with brightness, other data show CFF dropping off or reaching an asymptote in the vicinity of 60 cps.

Although the issue is not wholly resolved, certain values can be considered as reasonably safe approximations for standardization. In the case of head-up displays, where the background luminance is of high intensity and the display consists of discrete lines rather than a complete raster, CFF tends to be lower than it would be if a raster display and a dimmer background were used. One head-up display, having a refresh rate of 45 cps and a writing rate of 660 microseconds, has been flight tested without evidence of annoying flicker. In this instance, the green P 31 phosphor is of medium-short persistence, and the display subtends a 12° area of visual angle.

For a raster display with 2:1 interlacing, a repetition rate of 60 cps should be standardized. This is comparable to commercial TV values (Grob, 1964, Poole, 1966). For a line written head-up display a lower rate can be standardized (*e.g.*, 50 to 60 cps). However, the standard should not be rigid for all applications, but rather a reasonably firm guide to acceptable values.

A problem that arises in this area is that line written displays sometimes require the trading of brightness and display content for writing time. If the refresh rate is too high, the amount of symbology or the intensity of symbol luminance may be undesirably constrained. Therefore, the display designer should be allowed to deviate from design goal values if necessary. However, the burden of proof that a deviation does not create noticeable and annoying flicker should then rest with the display designer.

The choice of protective filter(s) also relates to CFF since directional filters can block adjacent seat exposure to display luminance. Thus, if the co-pilot becomes annoyed by the pilot's display or the reverse, a directional filter can be considered as a means to eliminate peripheral flicker. Although the literature is not conclusive about the exact shape of the high frequency and high luminance part of the CFF curve, we do not anticipate that the refresh rates which are recommended in this report will create objectionable effects.

Please note that threshold CFF and annoying or distracting flicker are not necessarily the same thing. The important factor is not at what point flicker just becomes apparent to 50 per cent or 90 per cent of a given population. The practical criterion is at what point does it become so noticeable that it is annoying or begins to affect performance, induce fatigue, or create similar deleterious effects. This value is a bit more elusive, but the recommended frequency levels of 50 cps for head-up, line written, and 60 cps for head-down, raster, displays should be quite adequate.

Before leaving this topic, the role of phosphor persistence characteristics in determining CFF should be mentioned. Turnage (1966) reports that much of the published data on flicker do not apply to CRT display design because they do not take phosphor persistence into account. He advises that the CFF for a phosphor-human system is reduced substantially from CFF values for dissimilar light sources. The following table shows how the seven phosphor types used in the Turnage study are ranked in terms of their ability to reduce flicker at the 100 ft L display intensity level.

TABLE 21 RANK ORDER OF SEVEN PHOSPHORS ACCORDING TO FLICKER CHARACTERISTICS AT THE 100 FT L LEVEL

PULSE MODULATION DATA	
PHOSPHOR	CFF in cps
P 12	32 (least flicker)
P 7	43
P 1	43
P 28	46
P 4	47
P 31	51
P 20	54 (most flicker)

(Adapted from Turnage, 1966)

These data indicate the P 1 has an advantage over the P 31 and P 20 phosphors for use in E/O displays because of its less pronounced tendency to cause flicker.

RESOLUTION

Resolution can be broadly defined as a measure of ability to delineate detail or to distinguish between nearly equal values of a quantity. Carel (1965) points out that there is no universal understanding of the precise meaning of the term. To illustrate the variety of meaning, he lists nine measures of resolution which range from radar resolution to ground target recognition. He also provides a table of resolution requirements for pictorial displays which is based on estimated ideal values. Carel's table is reproduced on the following page (Table 22).

Our purpose is not to present a detailed discussion of various types of resolution, generation techniques, conversion formulas, and the like. The Carel report has already covered this ground thoroughly. Our concern is to sample the evidence, specify the generic problems, outline the significant factors, and make whatever recommendations seem appropriate.

For convenience, E/O display resolution may be divided into a few broad areas by the following categorization.

1. Display generation constraints or limiting factors, such as field of view, display size, viewing distance, sensor and system component limitations, the resolving power of the eye (or an acceptable limiting criterion), and special weapon delivery requirements.

2. Recognition of ground objects.

3. Alphanumeric symbol generation, such as symbol size and the required minimum number of raster lines for character rendition.

4. Multisensor display considerations which relate to the display of information from two or more sensors on a single monitor.

5. Line written displays.

It seems evident from the different types of resolution, the variety of measurement techniques, and the tablulated estimates of display requirements, that a single resolution value should not be specified for standardization across all display types and for all display uses. This is not to say, however, that some compromise values cannot be reached for certain classes of displays. Carel (1965) recognizes this problem and cites his table of estimated display values as an example of *"a tremendous conflict in requirements depending on the intended use of the display."* He also

TABLE 22 - SOME REQUIREMENTS FOR PICTORIAL DISPLAYS

Display Type	Sensor	Nominal Sensor Characteristics		Representative Values for Raster Scan Display Requirements								
		Frame Rate Cps	Resolution Elements/ Diameter (d)	Field of View	Magnification Range	Approximate Size (1)	Data Rate Cps	Writing Speed and Field Rate	Storage Time Seconds	Resolution, & Standard TV Lines or Equivalent (1)	Shades of Gray [illegible]	[illegible]
Skeletal Vertical Situation	N.A.	N.A.	N.A.	Minimum AZ = ±20° EL = +15° to -20°	Limits 0.33 - 1.0	Mag. 0.33 | 1.0; AZ: 6° | 17°; EL: 5° | 15°	Translation 30 cps; Rotation 60 cps	TV Rates	Translation [illegible]; Rotation [illegible]	Mag. [illegible]; AZ [illegible]; EL [illegible] (2)	[illegible]	[illegible]
Contact Analog Vertical Situation	N.A.	N.A.	N.A.	Minimum AZ = ±30° EL = +15° to -20°	Limits 0.33 - 2.0	Mag. 0.33 | 2.00; AZ: 8° | 50°; EL: 5° | 30°	Translation 30 cps; Rotation 60 cps	TV Rates	Translation [illegible]; Rotation [illegible]	Mag. [illegible]; AZ [illegible]; EL [illegible] (2)	5	[illegible]
Literal Vertical Situation	(See Below)	(See Below)	(See Below)	Minimum AZ = ±15° EL = +15° to -20°	Probable Value 1.2	AZ: 15° EL: 18°	30 cps	TV Rates	(See Below)	AZ [illegible] EL [illegible] (2)	5 - 7	[illegible]
Map, Horizontal Situation	N.A.	N.A.	N.A.	N.A.	N.A.	8°	N.A.	TV Rates	N.A.	[illegible] (2)	3	[illegible]
Pattern Sensor, Horizontal Situation (also applies to literal vertical where appropriate)	Low PRF Air-to-air Doppler Radar (Synthetic Processing)	0.36	575	N.A.	N.A.	4.5° (5)	N.A.	TV Rates	2.0	[illegible] (3)	3	[illegible]
	Low PRF Air-to-air Radar 40 mile range; 5 mile range	0.33; 0.33	1460; 185	N.A.; N.A.	N.A.; N.A.	11°; 7° (5)	N.A.; N.A.	TV Rates; TV Rates	2.0; 2.0	[illegible] (3)	3; 3	[illegible]
	Air-to-air IR, C-scan	0.16	4300			20° (5)		TV Rates	6.0	[illegible] (3)	3	[illegible]
	Low PRF Radar Ground Map 40 mile range; 5 mile range	0.33; 0.33	1000; 625	N.A.; N.A.	N.A.; N.A.	8°; 5° (5)	N.A.; N.A.	TV Rates; TV Rates	[illegible]	[illegible] (3)	5 - 7; 5 - 7	[illegible]
	Radar GMTI	0.36	575	N.A.	N.A.	4.5° (5)	N.A.	TV Rates	2.0	[illegible] (3)	3	[illegible]
	IR Ground Map	Single Frame	690			5.5° (5)	N.A.	TV Rates	1.6	[illegible] (3)	5 - 7	[illegible]
	Side Looking Array Radar Synthetic Processing; Real Beam		280; 440			7°; 3.5° (5)		TV Rates; TV Rates	[illegible]	[illegible] (3)	5 - 7; 5 - 7	[illegible]
	Television - Standard; Improved	30; 30	[illegible]			6°; 5° (5)		TV Rates; TV Rates	[illegible]	[illegible]	5 - 7; 5 - 7	[illegible]
HUD	N.A.	N.A.	N.A.	AZ: ±15° EL: -5° to -20	1.0	N.A.	20	TV Rates	[illegible]	N.A.	3	[illegible]

(1) All size and resolution estimates based on 24" viewing distance
(2) Estimated from required display size
(3) Estimated from sensor resolution
(4) In a tradeoff, consideration should be given to making the elevation resolution [illegible]
(5) Estimated from display resolution

(reproduced from Carel, [illegible])

states that a single display device which satisfied all requirements would, indeed, be a Herculean achievement.

Although Carel suggests 1000 lines of display resolution as a general compromise between what is currently available and what he estimates to be needed, he does not make a full presentation of the evidence to support such needs. We are not implying that Carel does not specify the basis for his estimates, or that the estimates are not good ones. We do suggest that the human performance penalties to be paid for violating resolution requirements are generally not well documented in the literature.

Carel does relate the recognition of ground targets to certain resolution requirements. This is a useful performance criterion. Similarly, Shurtleff (1967) relates symbol size and number of raster lines to speed and accuracy of symbol identification. These are also useful performance criteria. However, what are the penalties if, for example, we provide only 500 vertical raster lines when 700 or 1000 are said to be needed? Are the penalties for degraded resolution of roughly equal severity for different classes of displays and mission tasks? We assume not; but, in many situations, we are forced to speculate as to the interaction of display variables and the severity of resulting performance degradation. Our point is that here, as in other areas, the display characteristic should be related to valid measures of human performance within the constraints of a realistic environment. In this way we can both predict man-machine performance and estimate the criticality or acceptability of hardware-related deficiencies. We can make intelligent design tradeoff decisions so that reliability, cost, and system effectiveness are given proper consideration.

Vertical and Horizontal Resolution

Varied definitions notwithstanding, it is popular to discuss raster generated E/O display resolution in terms of the total number of raster lines, or in terms of raster lines or picture elements per inch. In those displays that have the same resolution as commercial TV, vertical resolution is specified as 525 total raster lines. Blanking or fly-back time uses about 25 of these lines thereby reducing the total number to 500 active lines for one frame (i.e., each interlaced field has 250 active lines). Total active raster lines (500) divided by 8 inches (total raster height) yields a vertical resolution of 62 lines per inch.

On the other hand, horizontal resolution for raster generated E/O displays is calculated by multiplying active scanning time, in microseconds, by bandwidth, in megacycles, and their product by a multiplier of 2. The multiplier 2, which is basic to all information content equations, is necessary because each cycle has a maximum and a minimum state, which in the case of video means alternate black and white dots. This simplified explanation assumes that the raster is not being traced in a horizontal

progression. Rasters are usually generated in top to bottom sweeps of the electron beam. Hypothetical values are used below in an example of horizontal resolution calculation.

1.	Total scanning time	63.5	usec
2.	Blanking time	-12.0	usec
3.	Active scanning time (T)	51.5	usec
4.	Bandwidth (B)	3.0	megacycles

Beste (1963) offers the following method for calculating horizontal resolution. To find N, the total number of horizontal elements, where T is the active scanning time, and B is bandwidth:

$$N = 2\ (TB)$$

$$N = 2\ (51.5 \text{ usec} \times 3.0 \text{ mc})$$

$$N = 2\ (154.5 \text{ cycles}) = 309 \text{ elements resolvable horizontally}$$

The preceding formula and calculation are included to provide a simplified understanding of the differences between vertical and horizontal resolution. For more detailed treatments of resolution see Carel (1965) and a comprehensive television reference source, such as Fink (1952).

Fink, incidentally, suggests that the figure of merit which best describes the resolving power of a television image is not the vertical or horizontal resolution taken separately, but rather their product, which is proportional to the total number of resolvable picture elements in the image. We would add that if it were decided to use such a figure to evaluate the recognition of ground targets, both the number of elements or resolution cells placed on the targets (target definition) and the fidelity with which the target image is reproduced within the sensor-display system, (the modulation transfer function) would be appropriate considerations.

To summarize briefly, we have thus far indicated that resolution can be defined and treated in a number of different ways. The figure of merit to be adopted is related to the purpose for which a given display is being used. Contemporary vertical situation displays are being designed with vertical active raster line totals of between 500 and 700 lines on 8-inch rasters. These displays have, therefore, between 62 and 87 vertical lines per inch. If we compare such values to Carel's recommended 1000 line display, assuming that it has a similar raster size and 80 blanked lines, the result is a total of about 115 lines per inch. Carel is, in effect, suggesting that we improve *circa* 1967 displays by about 100 per cent. But, before imposing such a requirement on display designers, we recommend that a better understanding of the relationship between human performance and display resolution be developed.

If we accept, as some assume, that the eye's resolving power is limited to about 1.0 minute of visual angle, a display which generates 115 lines per inch approaches that limit. Note that 1.0 minute of visual angle translates to about 120 raster lines per inch at a viewing distance of 28 inches. Our view in this matter is the same as Poole's (1966); 1.0 minute is really a convenient approximation rather than a statement of a resolution limit. For point sources of light, thin lines, and vernier alignment tasks, the eye can resolve less than 1.0 minute of arc.

Alphanumeric Symbols

A somewhat different approach to raster line data is appropriate for alphanumerics. Although we have already treated Shurtleff's (1967) report in Chapter IV, his findings provide a meaningful way to evaluate the resolution of those raster generated displays which contain alphanumeric or comparable symbology. Shurtleff applied two principal criteria: accuracy and speed of identification. Following his own experimentation and a literature review, Shurtleff recommended a minimum alphanumeric symbol construction of 10 raster lines per symbol height for discrete symbols.

In an earlier report (Shurtleff *et al.*, 1966) it was stated that the visual symbol sizes required for 99 per cent accuracy of identification varied from 13 minutes of arc for a symbol comprised of 10 lines to 36 minutes for one composed of 6 lines. Although he does not comment on the number of raster lines, Poole (1966) suggests that 15 minutes of arc is the minimum acceptable display symbol size.

In relating these findings to existing display designs, we find that a 15 minute symbol is equivalent to about .125 inches at a typical 28 inch viewing distance. For displays which provide 62 raster lines per inch, only 8 raster lines would constitute a symbol of this size. On those displays which provide 87 raster lines, 11 raster lines would be available to construct a symbol of minimum size. Based on Shurtleff's data we would have concluded that the former resolution is not acceptable. A larger symbol, that is, more raster lines would be required for the 62 line per inch display.

EL Display Resolution

This topic is germane to the above discussion since electroluminescent segments are somewhat analagous to raster elements. As we have noted elsewhere, EL displays are being considered for cockpit applications. Peterson (1966) advises that 50 closely spaced EL segments per inch is the most that will ever be required under normal conditions for solid state flight displays. He also warns that solid state displays should provide the lowest acceptable resolution to augment driving circuit simplicity.

We are thus made aware of an RL limitation that is likely to restrict its usage as a CRT substitute. Unless comparative human performance data on RL and CRT display mechanizations are gathered, however, it will be difficult to specify the precise extent to which such a limitation applies.

Display Screen Size and Resolution Measurement

Cockpit space is limited and is likely to remain so, especially for tactical aircraft. Because of this, ideal display sizes are sometimes compromised. Present designs for head-down VSDs specify viewing screen sizes of about 5 inches vertically by 7 inches horizontally, although contact analog types may be a little larger. Tactical displays and some special purpose types, such as air-to-air IR, may range from 8 to 28 inches according to Carel's estimates. However, Slocum *et al.*, (1967) advise that displays which exceed 8 inches in diameter create serious space problems in tactical aircraft.

When display size is restricted by available space, it is helpful to estimate the effects of such constraints on the design. Whitham (1965) provides some handbook type charts which allow us to estimate rapidly the limiting effects of some basic display parameters on resolution. For instance, he relates viewing distance to display element size, viewing distance to symbol size, and display screen height to both element size and the number of elements or horizontal lines. Using one of his charts for a 1000 line display having a height of 5 inches, we find that the maximum element size is about 0.004 inches (4 mils). For a typical 500 line screen with a height of 5 inches, the maximum element size is double the above, about 0.008 inches (8 mils).

Approaching the problem from a slightly different direction, we can use an alternate Witham chart to determine the range of element sizes appropriate for a given viewing distance. At 28 inches, the chart shows that elements are neither too large nor below the limit of acuity (not defined) if they are between about 0.009 and 0.085 inches (*i.e.*, 9 to 85 mils). We can see from this that neither of the previously mentioned display resolutions is too large, although the 1000 line display exceeds the limit of acuity criterion Witham has chosen.

Unfortunately, the problems in resolution cannot yet be treated in such a straightforward manner. Slocum, *et al.*, (1967) hold that *"It would be desirable for the display system to have at least double the effective resolution of the sensor to minimize the loss in resolution in the combined sensor-display system."* Here, again, it would be helpful to have some specific human performance data to support such a contention. Nevertheless, the point is that the system and not the E/O display alone must be considered.

Another problem is related to measurement techniques and reaching some agreement about which method to use. Carel (1965) provided a comprehensive introduction to this problem, and Slocum and his colleagues tend to support

his analysis. They note, for example, that the 1000 TV_{50} lines specified by Carel appears to be reasonable after consideration is given to high resolution sensor performance, operator tasks, and system performance. They also note that 1000 TV_{50} lines is the same as 590 optical line pairs or 840 shrinking raster lines. This being so, we should adopt a particular method for defining the way that resolution is to be compared. According to Slocum *et al.*, the three most frequently used techniques for measuring resolution are these: *shrinking raster resolution, limiting television response, and spatial frequency response or modulation transfer function (MTF).* Their explanation of these techniques is given below.

> *"Shrinking Raster Resolution. Shrinking raster resolution is determined by writing a raster of equally spaced lines on the display and reducing or "shrinking" the raster line spacing until the lines are just on the verge of blending together to form an indistinguishable blur. A trained observer normally determines this flat field condition at about two to five percent peak-to-peak light intensity variation. Since the energy distribution in a CRT spot is very nearly gaussian, the flat field response factor occurs at a line spacing of approximately 2σ where σ is the spot radius at the 60 percent amplitude of the spot intensity distribution.*

> *"Television Resolution(TV Limiting Response). A television wedge pattern measures spot size by determining the point where the lines of the wedge are just detectable. The number of TV lines per unit distance is then the number of black and white lines at the point of limiting resolution. The wedge pattern is equivalent to a square wave modulation function, and therefore the TV resolution is often referred to as the limiting square wave response. (One needs to be careful to remember that, in television parlance, one cycle of the square wave produces a black interval and a white interval and is considered as two television lines.) Assuming a gaussion spot distribution, the limiting square wave response occurs at a television line spacing of 1.18σ. Thus, there are approximately 1.7 times as many limiting television lines per unit distance as shrinking raster lines for a display with the same spot size.*

"Modulation Transfer Function(MTF). The sine wave response technique of O.H. Schade...analyzes the display resolution by the use of a sine wave test signal, rather than the square wave signals employed in a TV test pattern or the photographic bar patterns commonly employed in the optical field. The sine wave response test produces a curve of response called the modulation transfer function (MTF). ... When several devices are cascaded such as a scan converter video amplifier and CRT, the MTFs of the individual devices are multiplied together to determine the total system MTF. The MTF response can be related to the shrinking raster and television resolution measurements if a gaussian spot shape is assumed. ... For example, if a sine wave test signal were set on the display at a half cycle spacing corresponding to the shrinking raster resolution line spacing, the resultant observable modulation on the display would be approximately 29 percent."

Wurtz (1967) also refers to the ambiguity surrounding the meaning of certain statements of resolution. He notes that the claims of manufacturers concerning high resolution CRTs are sometimes misleading. A specified spot size of 0.001 inch (1 mil) does not necessarily mean that the systems designer has 1000 elements to the inch. Wurtz advises that we must take into account the follow factors:

"(1) The method by which the resolution is to be evaluated

(2) The degree of response of modulation depth required for a given resolution

(3) The spot size at the light output (hence, beam current) required for the application

(4) Deflection focusing."

Wurtz also advises that the measuring method and modulation depth are tied together and that the shrinking raster method is commonly used because it is easy.

We are reminded here that Clauer (1966) and Carel (1965) have cited the usefulness of the modulation transfer function for establishing system resolution. In addition, Clauer finds certain MTF characteristics to afford a reasonable method for stating resolution from the observer's viewpoint.

Our concern is not in deciding which method is most appropriate and appealing to display designers or users. Rather, we are interested in having a commonly understood statement of resolution (and/or acceptable conversion formulas) to minimize ambiguity, to take into account the sensor-display system, and to relate to operator performance.

Before leaving this general topic we will add this comment about the Whitham charts mentioned earlier. Whitham (1965) properly cautions that his --

> *"...discussion is limited to two-dimensional displays with a highlight brightness range which permits employment of normal photopic vision. The discussion does not consider low contrast, gray scales, color, and viewing angles other than normal to the display surface."*

We find that the above quote is somewhat typical of the data that are available in the literature. Our choice is either to accept estimated values of required resolution for whatever they are worth, or perform research ourselves to improve upon them.

The latter is necessary if we are to establish firm data which can be generalized to various situations and used as the basis for performance criteria.

Multisensor Displays

Several reports have treated the complications that are caused by the recent trend in military aviation which requires using a single monitoring device to display signals from two or more sensors, each of which may have a different resolution. Harsh (1966) cites the time differences required to synthesize a complete frame from various sensors as one such complicating factor. This requires that the multisensor system have the capability of variable image persistence, which must be consistent with the data rate of the sensor being monitored.

Harsh gives the following as a typical list of modes and persistence classifications:

Mode	Persistence
Terrain avoidance (shades of gray)	Medium
Terrain following (E-scan)	Medium
Flight situation (contact analog)	Short
B-scan radar	Long
LLLTV	Short
PPI (terrain mapping) radar	Long
Infrared	Medium

He goes on to note that these are two possible solutions to the persistence variability problem:

1. The Display Storage Tube (DST) which affords short persistence for TV data rates (a few milliseconds) and longer persistence for the radar modes.

2. The Scan-Conversion/Cathode-Ray Tube (SC/CRT) which converts signals from various sensors to a TV time base.

Each of these approaches has its advantage and disadvantages, depending on the application.

Harsh summarizes his conclusions this way:

> *"The foregoing analysis suggests that display of radar signals can be handled at least as effectively by the SC/CRT approach as by the DST approach In some respects, e.g., uniformity, resolution, and ease of setup, the SC/CRT approach can be made to have advantage. In terms of the number of system components and possibly in power consumption and display luminance, the DST approach may be more attractive... .*
>
> *"1. The SC/CRT approach appears to offer:*
>
> *a) Superior display quality in short-persistence modes of operation, e.g., TV modes,*
>
> *b) At least an equivalent display quality in longer-persistence modes of operation, e.g., radar modes,*
>
> *c) Considerable flexibility for future system modifications and additions.*
>
> *"2. The DST approach appears to offer:*
>
> *a) Higher luminance output in some modes of operation,*
>
> *b) Fewer system components,*
>
> *c) System space and weight advantages. (Note: This advantage is valid only in a multisensor system having a single final display of relatively small size...probably in the range of 6 to 10 inches.)"*

Referring to the same general problem as Harsh, Slocum *et al.*, (1967) point out that although a fading erasure technique is adequate for low resolution ground mapping radar systems, selective line-by-line erasure is required for small target recognition at aircraft speeds of 1000 feet per second.

On image storage time, they have this to say:

> *"The display storage time requirements vary from 1/60 second for non-flickering bright TV displays to two seconds for some radar PPI scans or as much as one to two minutes for side looking strip mapping radar. In addition, it is highly desirable to allow the operator to hold or store an image for more detailed examination and target designation with cursors. This display mode may require image storage for two to five minutes."*

The above references are cited to emphasize again that display system requirements for resolution are quite variable and must be related to the mission of the aircraft and task performance requirement of the pilot. Without these data and considerably more experimental evidence than we have found in the literature, it will be difficult, indeed, to provide more than general guide lines and estimates in support of a standard.

Line Written Display Resolution

This subject will be treated briefly because it does not represent a formidable problem in E/O display design. Most line written displays are of the VSD head-up type, although head-down VSDs, HSDs, and others may be generated in the same way.

Vernier alignment and the discriminability of symbols in close proximity are the kinds of problems which are likely to be found in such devices. The symbols should be sharp enough and the lines wide enough to be seen against the display background. Yet, symbols should not consist of lines which tend to obscure one another or real world objects of interest. Thus, the perceptual problem in line written displays is usually not how finely is the symbol drawn, but rather how great must the line width be in order to insure good symbol visibility. It is, therefore, somewhat the reverse of the resolution problems encountered with raster type display Severe *blossoming* of spot size with CRT age or halation effects are to be avoided.

Although the line width depends somewhat on the precision demanded in a given display usage, an approximation for guidance purposes is about 3 to 5 minutes of visual angle. For direct view displays this is equivalent to a line width of 0.024 to 0.040 inches at a viewing distance of

28 inches. For projected displays line widths may be specified in terms of visual angle or in equivalent line widths at the CRT surface.

An Approach to E/O Display Resolution

Whether or not a systematic attempt is made to specify the parameters of resolution, we must deal with them as effectively as we can. This report has cited several experts in the field who have stated the complexities of resolution and who have given us their best estimates of ideal and tradeoff values for display design. We believe that the following is generally consistent with their holdings:

1. A systems approach should be taken. Attempts should be made by the designer or user of a display to determine the kinds of sensors that will be used in a given weapon system. If more definitive data are lacking, the most stringent sensor resolution problem should be identified and the rule of thumb that *"display resolution should be twice that of the effective resolution of the sensor"* may be applied. (Slocum *et al.*, 1967).

2. If sensor data are lacking but mission requirements are known, an attempt should be made to relate the most stringent mission and task requirement to display capability.

3. If the above seem inappropriate, an attempt should be made to specify whether or not a TV mode will be used and what the purpose of that mode will be. The recognition of ground targets, for example, might dictate that a given level of resolution is required.

4. For those displays which provide only stylized symbology for head-down, VSD type command and attitude information, the 500 raster lines now commonly specified for such displays are probably adequate. If the addition of multisensor capability is anticipated, resolution approaching Carel's 1000 lines might be used.

5. If alphanumeric symbols are to be displayed, an attempt should be made to apply the findings of Shurtleff and his colleagues (1966) so that an adequate number of elements per symbol height are provided.

6. In all instances the size of a display and viewing distance should be related to Witham's charts to determine that the planned design will not create symbol elements that are too large or so tiny that they represent an unwarranted overdesign.

COLOR

Excepting colored map presentations, a general use of color is not found in contemporary E/O displays. The absence of color producing devices is not from a lack of need since there are definite uses to which color is well suited. At least part of the answer, undoubtedly, is to be found in technological limitations, some of which are now being overcome. Pizzicara's (1966) display survey outlines about a dozen color generating techniques which were then in use or feasible to produce. His view is that, in the absence of a breakthrough in an area such as solid state displays, CRTs are likely to dominate the color field for some time. Of the methods of creating color on a CRT, Pizzicara favors the shadow mask tube, which is that used in current commercial TV. This technique makes use of an electron gun for each phosphor. It has the advantage of a small angular separation between the electron beams, thus providing good registration of the respective rasters.

In a more recent article, Damon (1966) reports on a high resolution color storage tube. It is said to overcome the limitation of delicate target-to-phosphor alignment, characteristic of previous designs, and to provide two colors in a rugged tube which is not unreasonably costly. Damon supports the need for this device by citing its possible application to radar, sonar, computer readout and other specialized displays. He recognizes the general need for additional research in this area and concludes:

> *"The efficacy of color in many display situations is not known. It will require experimental evaluation by human factors engineers and others to determine where use of this color storage tube is warranted. The reasonable manufacturing cost of the tube and associated circuitry will aid in its acceptance. The high resolution, simplicity of input signals, use of only one video gun and rugged design make available for the first time a versatile color storage tube capable of satisfying military and industrial requirements."*

In one of the few research studies which relates the effects of display phosphor color to human performance, French (1967) found that an abrupt change of target color, at the time a target traversed a display sector boundry, did not enhance target detectability. In fact, the reverse was true. A constant color was found to be easier to detect. French also found that of eight commonly used radar and television phosphors (P4 gray, P 12 orange, P 20 yellow-green, P 22 B blue, P 22 G green, P 25 orange, P 28 yellow-green, and P 31 green), the three phosphors with highest target detectability (P 12, P 25, and P 28) all have relatively short persistence. The separate roles of persistence and color are not

established by French, and we cannot speculate on possible causal relationships. Nevertheless, much more research can and should be done to relate phosphor color to task performance.

There are at least three areas where the use of color can be expected to contribute materially to E/O display design.

1. As a coding dimension - This topic was treated in Chapter IV.

2. For perspective effects - Contact analog and terrain avoidance displays may profitably make use of color to improve perspective or to create quasi-three dimensional effects.

3. For improving display legibility - In high ambient light conditions, monochromatic presentations often encounter problems of luminance and contrast; the use of color may afford a way of relaxing these demands and at the same time improve target detection and recognition.

There is wide agreement that the addition of color would enhance the usefulness of E/O displays. However, there is less certainty about the use to which color should be put and the nature and magnitude of the improvements to be expected. Empirical data are needed on the relation of phosphor color to such variables as target detection, symbol legibility, display interpretation, flicker, luminance, contrast, and so on. Such information, were it available in handbook form, would help designers to make intelligent tradeoffs and to improve displays that, in their present monochromatic form, are marginal.

Several designers to whom we talked in the course of this study expressed the opinion that practical airborne color displays are attainable within the next three to five years. The survey by Pizzicara (1966) indicates the great variety of techniques that could be used to attain this end, and the report by Damon (1966) describes a multi-color storage tube CRT that has recently been introduced. Much more could be said about color and its promise in the E/O display field. However, because multi-color CRTs are now only in an emerging state and because there is a relative paucity of established empirical evidence, we do not believe it is appropriate to enumerate standardization requirements. We would prefer to know more about the relationships between color and other display characteristics and human variables before making comparative judgments about color techniques and about the suitability of multi-color displays to military aircraft needs. We would urge, however, that research in this area be undertaken promptly if we are to avoid some of the problems which plagued the development of monochromatic CRT displays.

OPTICS AND FIELD OF VIEW

The topics of display size and field of view as they relate to direct view displays have been touched upon in this chapter in the section dealing with resolution. Our present concern is with projected head-up displays which present certain field of view problems that may properly be treated as display characteristics. These arise from the fact that head-up displays make use of optically projected images which are reflected from a transparent surface. In addition, the reflecting surface must usually be fitted into a narrowly restricted area and must allow for an adequate field of vision through a range of aircraft attitudes. Thus, the optical system forms a part of the image generation train, and its characteristics deserve some attention in this chapter.

There are basically two optical systems in popular use for projected, head-up displays: the *extended pupil system,* which uses a curved combiner, and the *gunsight* system, which uses a non-spherical (usually flat) combiner. Both types make use of collimation to create an image which appears at optical infinity. Thus, the symbols of the display do not appear to be on the transparent combining element but at a great distance ahead of the aircraft where they are superimposed on the real world view. A schematic representation of these two systems is shown in Figure 24.

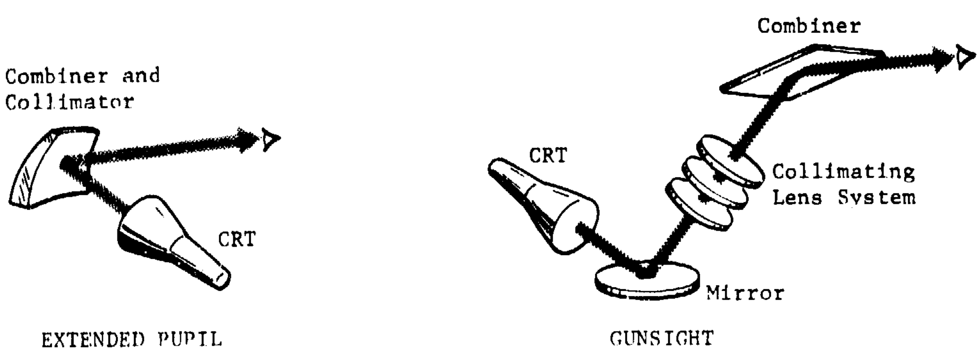


Figure 24 HEAD-UP DISPLAY OPTICAL SYSTEMS

It should be noted that the integrated collimator and combiner in the above illustration of the extended pupil system is not a necessary feature of this type of system; the two components may be separate, as they are in the gunsight system illustration. The integrated collimator-combiner is shown simply to indicate that such an option exists. It makes no difference in the following discussion.

The extended pupil system has the advantage of allowing greater freedom of head movement for the pilot without concomitant restrictive changes in his field of view. In effect, the pilot is provided with a comparatively large binocular field of view in the lateral dimension. A 25° lateral binocular field of view is typical of that attainable for such systems.

Ideally, the most desirable type of symbol reflector (combining glass) for such a system would be a sphere centered about the pilot's head. Symbols would be projected to the sphere on axis so that *keystoning* distortion would be minimal. In practice, however, these conditions are not attainable. The symbols are projected off axis and the combiner is fixed in place. Furthermore, pilot head movement can result in additional distortion. Those who favor the extended pupil system maintain that windshields in modern high performance aircraft distort one's view of the external world anyway, and extreme accuracy of symbol placement or lack of distortion at the combiner is an unwarranted constraint. They want proof that whatever degradation of symbol images, lack of accuracy in symbol placement, or distortion of external visual scenes which may be attributed to their technique has a significant effect on performance. We do not have such proof. Distortions in their system may indeed be minute compared to windshield curvature effects.

Whatever view one may take of this, it might also be noted that although a wide lateral field of view is generally desirable for head-up displays, it has by no means been proved that pilot performance is significantly better with a few more degrees in this dimension. How much better, if any, does one perform with a 25° lateral field of view than with a 20° or a 16° field? Greater flexibility is required in the vertical dimension, but performance data are not available in either case. At any rate, there are other factors to consider. The extended pupil system uses curved combiners that tend to be both heavy and bulky. In addition, the projecting hardware, that is, the equipment from which symbol images are projected, juts out into the cockpit near the pilot's chest. This is a potential safety problem in those cockpits which use seat, rather than capsule ejection. Such projections also tend to restrict vision and may hamper the operation of some controls.

The gunsight optical system also has its advantages and disadvantages. Among the advantages are its reduced weight and bulk and its on-axis projection. One of the disadvantages is that the exit pupil of the optics unit is some finite distance ahead of the pilot, thereby creating a knothole (an optical aperture) through which he must look. Head movement can

cause symbols near the periphery of the instantaneous field of view to be lost while the head is in the unfavorable position. In addition, a wide field of view is difficult to obtain since a wide flat combiner will not fit into the windshield areas of many tactical aircraft. Also, the exit lens aperture would have to be excessively large for such a device. A total field of view on the order of 20° is probably the most that can reasonably be expected of flat combiner systems and 16° is usually the attainable figure. One expert with whom we consulted estimated that a 10° field of view is marginal, 15° is acceptable, and 20° is quite reasonable for head-up displays. He noted that a 25° total field of view is the largest that he has ever heard of and that the penalties for a field of this size are excessive in terms of combiner bulk and weight.

In fairness to proponents of both the gunsight and the extended pupil systems, it is necessary to point out that the importance of freedom of head movement may be exaggerated. While it is true that pilots may be expected to make far ranging head movements while flying, it may not be reasonable to assume they will do so at the same time as they view a head-up display. Further, it is unlikely that pilots will want to move about while performing a demanding maneuver for which a head-up display is intended to serve as a primary reference. Therefore, some mild constraints on lateral head movement are not thought to be unwarranted. Until some evidence is presented to establish a definite connection between performance degradation and relatively minor limitations of the lateral field of view, we should be more concerned about providing an adequate field of view in the vertical dimension (particularly over the nose of the aircraft).

Certain generic problems of head-up display optical systems are now being investigated by Theodore Gold and his associates at Sperry Gyroscope. Without going into detail, we list some of these study areas below.

1. Absolute tolerance for binocular disparity.
2. Effects of symbols with image disparities overlaying the real world.
3. Visual discomfort as a function of binocular image disparity resulting from changes in head position and viewing angles.
4. Magnitude of permissible image disparity at the boundaries of monocular and binocular fields of view.
5. The effects of retinal rivalry (eye dominance).
6. Tolerance for collimation error (*i.e.*, accommodation problems when less than infinity collimation is attained).
7. Minimum exit pupil size.
8. The effects of changing lateral head position.

Physiological Diplopia

A potential problem, which may be part of the collimation study mentioned above, is that of physiological diplopia. The condition of diplopia (doubling of vision) derives from the fact that a normal two-eyed individual is unable to keep fixated simultaneously on a near and distant target.

Actually, it is a problem of depth perception. The phenomenon disappears with the use of one eye and tends to diminish in frequency and severity as the near object approaches the distant object.

The situation is that images on the head-up display combining glass are optically focused to create the illusion to the observer that they are placed at infinity. However, this illusion is subject to breaking down if collimation is inadequate or if there is a preponderance of cues as to the nearness of the combining glass. As yet, no such difficulties have been reported, but they are theoretically possible, and it would be well to remain alert to this phenomenon.

STANDARDS OF MEASUREMENT

This section lists the more important units and measurements which we believe to be appropriate for an E/O standard. Some are obvious and are given only as a reminder. Some, such as luminance, are treated in detail in other parts of the report and are simply summarised here. Others are mentioned for the first time and require explanation. All are stated as concisely as clarity of description allows.

1. The angle subtended at the eye is recommended as the unit of measure for symbol size on projected and direct view displays. In the case of projected displays there is no practical alternative, and so the recommendation implies nothing more than a continuation of current practice. For direct view displays linear measure is frequently used. While there is nothing necessarily wrong with this, the practice can lead to confusion if viewing distance is not specified also. We have encountered more than one report which treat symbol size for direct view displays in some detail but which fail to indicate the observer-to-display distance. In the interests of uniformity and clarity, therefore, we recommend that visual angle (the angle subtended at the eye) be used as the unit of measure for symbols on all displays. We further recommend that viewing distance also be specified for direct view displays since the angle subtended by a symbol of given linear size varies as a function of viewing distance. To obtain the angular equivalent for a direct view display symbol of a given linear dimension, apply the formula:

$$\alpha = 2 \arctan \frac{h}{2d}$$

where α = visual angle

h = linear symbol dimension

d = viewing distance

To convert from angular to linear measure, apply the formula:

$$h = 2d \tan \frac{\alpha}{2}$$

2. Field of view is a term which is subject to some misunderstanding because of the variety of meanings assigned to it. We recommend that *field of view* be used to designate the solid visual angles

subtended by the display and that the term also be qualified so as to distinguish between *monocular* and *binocular* fields. This is particularly important in the case of head-up displays, where it is also necessary to distinguish further between *instantaneous* and *total* fields of view, where the former denotes that field of view available at some given eye position and the latter denotes that which it is possible to obtain by moving the head to a number of positions. Thus, it is possible to speak of a head-up display of such and such an instantaneous monocular field of view or a head-up display whose total binocular field of view is thus and so.

There may be several eye positions associated with a given display, each related to some activity or pilot sitting position. It is not uncommon to encounter terms such as *erect eye, relaxed eye, normal flight eye, landing eye, HIAD eye,* and *design eye,* several of which may be used in connection with one display. It is important to specify which of these has been used for determining the field of view of the display.

We also wish to discourage the practice of using field of view to mean that portion of the real world scene represented within the boundaries of the display. That is, a direct view VSD whose dimensions are 6 inches by 8 inches will subtend a viewing angle of 12° X 16.5°, but it may represent 35° X 40° of elevation and azimuth in the real world. To call the latter the field of view of the display can only lead to confusion. We believe it preferable to employ a term such as *field of coverage* to designate the angular dimensions of the real world scene portrayed on the display.

3. Viewing distance for panel mounted displays is often taken to be about 28 inches when not otherwise specified. This is the same approximate distance commonly used for conventional aircraft instruments. However, for rotary wing aircraft the pilot may sit much closer to the display. For such aircraft, a different rule-of-thumb estimate is needed, something on the order of 18 to 20 inches. It is helpful to establish commonly understood values of this sort for use in situations where displays must be designed or evaluated without specific knowledge of cockpit geometry.

4. Luminance of displays should be expressed in foot lamberts (ft L) or in millilamberts (mL). The two units are nearly equivalent; 1 ft L = 1.076 mL or 1 mL = 0.929 ft L.

5. Illuminance, the light falling on a surface, should be expressed in foot candles (ft C).

6. Boresighting procedures for aligning projected head-up displays should be developed and specified. Equipment accuracy, alignment method, and frequency of alignment verification are important factors to be considered. Note that handles should be mandatory for avionic displays and

in particular for those head-up displays which must be accurately boresighted. Unless handles are provided, combiner mounting supports or some other inappropriate substitute are likely to be used as hand holds, thereby risking an inadvertant change in factory, bench, or cockpit alignment of the display.

7. Symbol accuracy can be specified in several different ways. Static positional accuracy, size accurary, and dynamic accuracy are three that may be used. The basic recommendation here is that the specification of tolerances and accuracies be guided by common sense and a realistic appraisal of the use of the symbol. For example, if a steering symbol has been deflected away from its null position to some point on the display which represents a gross command steering change, a very restrictive accuracy and tolerance stipulation at that magnitude of deflection is unnecessary, and unwarranted. It is more important for such a symbol to have its best positional accuracy near the null point. Error expressed as a percentage of deflection magnitude is suggested as the appropriate method of specification for such cases. On the other hand, a symbol such as the impact point or velocity vector, when used in terrain avoidance or landing, should be accurately positioned at any place on the display. More specific comments are beyond the scope of this report and are somewhat a function of particular weapon system and mission requirements.

8. Display parametric units, *i.e.*, the units in which displayed information is expressed, are the commonly accepted ones now in use by the military services. They are presented here merely as a reminder that these conventions also apply to E/O displays.

Altitude is expressed in *feet*.

Vertical velocity is expressed in *feet-per-minute*.

Pitch and *roll* are expressed in *degrees*.

Heading is expressed in *degrees*.

Angle of attack is normally expressed in *degrees*. However, for compatibility with conventional cockpit angle of attack indicators, it may be desirable to use the arbitrary unit specified for such devices, *i.e.*, the "angle of attack unit".

Airspeed is expressed in *knots*, or in *mach number*.

As a general rule, we recommend that all flight and propulsion parameters that are expressed as units of measurement be in accordance with MS 33636.

UNDESIRABLE QUALITIES

E/O displays sometimes exhibit unsatisfactory image qualities which result from factors inherent in the generation process. These are largely engineering problems, the details of which lie beyond the scope of this report and the solutions to which are not within our competence. We mention them in passing here simply because these undesirable qualities will affect the overall utility of the display for the observer and because they will be of concern to those writing a standard for E/O displays. As a summary judgment, we believe these undesirable qualities should be eliminated if at all possible. In cases where they are unavoidable, the design of the display should be such that their effects are minimized. Certainly, any standard which may be written for E/O displays should include specific provisions on these items.

Broadly speaking, the image degradations arise from two sources: within the display system or from interface equipment and the electronic environment. This division is not clear cut, however, and it is sometimes difficult to tell from looking at the display alone just where the source of the degradation lies. Such is the case when display symbols oscillate randomly about a point (jitter), when they creep away from a fixed position, when symbols deform, tear, or break up, when they pulse in size or brightness, or when they exhibit other such noise effects. Within the display system these defects are traceable to faulty circuitry, deterioration of components, or transient signals. They can usually be eliminated by careful engineering and proper maintenance procedures. More commonly, however, these deficiencies arise from electromagnetic interference and noise generated by interface equipment or by other electronic equipment located in proximity to the display. This is one of the most vexing problems in present sophisticated aircraft systems, and increasing attention is being devoted to it by electronics engineers. Evidence of this concern is also shown in the newly issued MIL-STD-461, MIL-STD-462, and MIL-STD-463 which provide for greatly increased effort to eliminate EMI and for more extensive system testing and demonstration.

Another common sort of image degradation produced outside the display system itself is a symbol which fluctuates about its fixed or null position or which is displaced by a constant amount from such positions. The fault here is attributable to errors in the data sensing or processing equipment which drives the symbol. These errors may be random and short-term (less than two seconds), in which case it is difficult to distinguish their effects from those of noise or EMI. The errors may also be longer term, *i.e.*, they may persist at a constant value throughout a duty cycle or flight regime, but still be random in nature in that they will vary from duty cycle to duty cycle. This is usually the case where symbols depart from their normal positions, or refuse to return, thus giving an indication of flight control error when, in fact, none exists. Speed indicators on E/O displays typically

exhibit these problems because of errors inherent in the pitot-static system which senses airspeed and because of calculation errors or inaccuracies in the air data computer which processes raw pressure data to obtain true airspeed, mach number, or groundspeed. No generic solution to this problem is available, although some relief can be found by adjusting symbol sensitivity to allow for random data input errors, by smoothing (averaging) data system outputs, or by creating a "*dead band*" around the presently indicated value whereby the symbol will not move unless the data input differs from the present value by an amount exceeding inherent data system error.

Within the display system one of the most frequently encountered problems is distortion of the shape of a symbol as it moves across the display or distortion of the entire image field near the edge of the display. These are functions of the linearity and accuracy of the CRT and depend upon the radius of curvature of the screen, the type of deflection used, and the maximum deflection angle. For tubes using electrostatic deflection the image will be undistorted only on a flat screen. With curved screens the image will suffer from *barrel distortion*. With electromagnetic deflection an undistorted image is produced only on a tube whose radius of curvature equals the deflection radius. Since most magnetic deflection CRTs have a screen radius much greater than the deflection radius, they usually exhibit what is known as *pincushion distortion*. This is most pronounced with tubes having wide deflection angles. Pincushion distortion can be corrected by using predistorted waveforms or special correction magnets, but with a sacrifice in absolute linearity. Electrostatic tubes, if flat-face, offer relief from distortion, but they suffer from deflection defocusing. The use of small deflection angles results in increased tube depth and, hence, is unsuitable for most airborne applications. Thus, it appears that some distortion is inherent in all CRT systems and must be accepted. However, an E/O display standard should emphasize the need for application of techniques to keep such distortion to a minimum.

Smear is another problem encountered in E/O displays, especially multisensor displays which have greatly varying storage times and data update rates. Smear is basically a problem of phosphor persistence and results from a severe mismatch between decay time and data update or symbol movement. For single purpose displays smear need not be a significant problem since there is a wide variety of phosphor persistences to choose from, 0.12 microseconds for P 16, to 16 seconds for P 26. If a particular color is desired, the choice is more limited, but there is usually sufficient latitude to allow for selection of a phosphor whose decay time matches other system requirements. The problem emerges with multisensor displays which may require 2-3 second storage time for IR data but also demand short persistence for LLLTV or missile video. We can offer no solution to the problem beyond the general one of suggesting that, in addition to other characteristics, designers give attention to persistence when selecting a phosphor and that they weigh their choice against display dynamics and data update rates.

For some direct view vertical situation displays the rotation of the horizone line to denote aircraft roll is accomplished by rotating the entire display raster. For others, the raster remains stationary, and roll is portrayed by drawing lines diagonally across the raster. On the latter the horizon line will be parallel to the raster only when the aircraft has its wings level. With such displays the horizon line (or any other horizontal ground-stabilized elements, such as pitch reference lines) will exhibit a moiré effect, *i.e.*, appear to shimmer or scintillate, if the aircraft rocks slightly in level flight or if there is even a small amount of noise or variation in the inputs from the attitude sensing system. Exposure to this scintillation throughout a long flight may well prove distracting or fatiguing. One method of overcoming this is to orient the raster vertically rather than horizontally. The moiré effect occurs only when the angle between the raster lines and the horizon line is small. Since with a vertical raster the horizon line will usually be perpendicular to the scan lines, scintillation will not occur except in the rare case of a 90° roll angle. One fault with this solution is that any vertically oriented symbol, such as a roll pointer, will now exhibit the same moiré effect. The problem is, of course, not confined to vertical situation displays. It will occur with any display on which lines must be drawn nearly parallel to the lines of the raster. This seems to be an inherent difficulty in raster displays; and while there is no solution for it, the possibility of moiré effects should be kept in mind when selecting a display generation technique and when devising symbols for raster displays.

Head-up displays suffer from a variety of problems which affect the quality of the image. A number of these result from imperfections in the collimating lens and other parts of the optical system and were discussed earlier under Optics and Field of View. Apart from these, one of the most significant deficiencies of head-up displays is their proneness to angular vibrations of the combining glass or other mechanical reflecting surfaces, which will produce an image that dances or jitters. This effect is aggravated by the collimation of the optical system, which causes the symbols to appear at infinity. Thus, because of the distant focus, small angular vibrations may appear to be large linear excursions and give an exaggerated impression of symbol or aircraft motion. Rigid mountings will overcome some of the vibration problems, but it is doubtful they can be eliminated altogether because of the magnitude and variety of stresses exerted on the combiner and mounts in high performance aircraft. The effects of symbol drift, system noise, and data input errors mentioned earlier are especially severe for head-up displays in that they produce misregistration of symbols and their real world counterparts. Studies of the effects of misalignment upon tracking performance were discussed in Chapter IV in relation to display dynamics, but the full import of misalignment has not yet been examined, especially as it pertains to weapon delivery and similarly precise flight maneuvers. We raise the point again here in order to emphasize the need for careful attention to the problems of image distortion, noise, and misalignment in head-up display design.

SUMMARY OF DISPLAY CHARACTERISTICS

This chapter has reviewed the diverse problems, considerations, and variables which may act either independently or in combination on E/O display performance. An eclectic approach has been taken to survey what is recognized to be a many faceted subject. We have assumed that both a broad look at the general issues and a precipitation of the essential ingredients therefrom would best serve our purpose. Experts in the field of E/O displays have been directly consulted, we have examined the published reports of still others, and we have drawn continually on our own experience. Walter Carel's original efforts in this area have been heavily leaned on, as have those data found in Society for Information Display (SID) journals and proceedings. But, even so, we admit that only a few tangled threads have been pulled away from the knot. JANAIR, in general, and a standardization group, in particular, still have a formidable task ahead. Although some display characteristics are reasonably well established, the majority seem to require additional research before we can specify valid and reliable limits. In the meantime we must be aware of existing specifications and use them with appropriate caution.

The above evaluation is somewhat parallel to our summary estimate of the situation for information requirements and symbology. That is, empirical research has established that certain display characteristics and parametric values are necessary or desirable. However, the characteristics and values encountered in contemporary display designs do not always accord with those specified by research. In the area of display characteristics, as elsewhere, we find that specific requirements derived in the laboratory are subject to modification in light of aircraft mission requirements, overall system constraints, and hardware limitations. Given these factors, it seems appropriate to offer as a final point a summary of the characteristics of some contemporary display designs. Table 23 lists the characteristics of the displays which were analyzed for information content in Chapter III. We leave an interpretation of their suitability to the reader, to operational experience, and to those who will conduct further research in this area.

TABLE 23 - DISPLAY CHARACTERISTICS

RASTER DISPLAYS NAME	TYPE	TOTAL WEIGHT	DISPLAY VIEWING DIMENSIONS Ht x Wd	APPROXIMATE ANGULAR COVERAGE PITCH	 HEAD.	APPROXIMATE COMPRESSION FACTORS PITCH	 HEAD.	NOMINAL BRIGHTNESS	CONTRAST	RESOLUTION HORIZONTAL	 VERTICAL	 SPOT SIZE	 LINE WIDTH	FIELD RATE INTER-LACE	FILTERS	CO
ADI(A-6A)	• Raster • Direct View • Head Down • VSD	49 lb	6 x 7 1/2	30°	50°	1:3	1:4	500 ft L	10 shades of gray in terrain avoidance mode		500 lines			60 cps 2:1	Micro-mesh & Red	An re ti
VDIG DVI (Direct View Indicator)	• Raster • Direct View • Head Down • VSD	70 lb approx (DVI & HUD total)	5.3 x 7	50°	75°	1:6	1:5	550 ft L in 10,000 ft L background	7 distinct steps between CRT luminance limits	450 lines	525 lines See Notes			60 cps 2:1	Micro-mesh & Red	An re ti
TID (Tactical Information Display)	See Notes for All Columns															
AAAIS VSD	• Raster • Direct View • Head Down • VSD	105 lb (prototype)	9 x 12 (13 diag.)	16°	22°	1:1	1:1			350 lines	500 lines			60 cps 2:1	Micro-mesh or Polarized	No Sp if
IHAS HSD	• Head Down • Direct View Storage Tube • HSD	62 lb	nom. dia. 6 use dia. 5.75 min.	NA	NA	NA	NA	1500 ft L, min.		At least 460 lines at any point on display					Red	No Sp if
IHAS VSD	• Raster • Direct View • Head Down • VSD	61 lb	5 x 7 min.	54°	72°	1:5	1:5	1000 ft L with 10,000 ft L background	7 shades of gray capability*, 4 shades used in contact analog mode (% of max) Shade Brightness Bright 95% ±5% Med. gray 50% ±10% Dark gray 20% ±10% Black 2.5% ±2.5% 7 gray shades for 5 contour lines in terrain following (a/a) avoidance mode	500 lines For terrain following see Notes	450 lines min.			60 cps 2:1	Micro-mesh & Red	No Sp if
ILAAS HSD	• Head Down • Direct View Storage Tube • HSD	68 lb max.	nom. dia. 5 use. dia. 4 min.	NA	NA	NA	NA	DVST 1200 ft L PPI line: 1000 ft L	Not Specified (PPI, Missile TV) 6 gray shades Brightness ratio between shades 1.4:1	Not Specified Center: 120 l/in. Edge: 100 lines/in (Miss TV)	Not Specified 80 lines/in. (Missile TV)	See Notes	.01 in. max. (PPI-J E-scan)	40 cps 2:1 (Missile TV)	Red	A
ILAAS VSD	• Raster • Direct View • Head Down • VSD	59 lb max.	5 x 6 5/8 min. 7 1/4 diag. min.	25°	35°	1:2.5	1:2.5	150 ft L to 1.5 ft L range with micromesh in place	(% of max) Shade Brightness Bright 100% +0% -5% Semi-bright 60% ±5% Light 34% ±4% Light gray 18% ±3% Gray 9% ±2% Dark gray 3.5% ±1% Black 0(.0001 ftL)	Not Specified	Not Specified	.030 in at max. brightness		Not Specified	Micro-mesh & Red	A

HEAD-UP DISPLAYS NAME	TYPE	TOTAL WEIGHT	TOTAL FIELD OF VIEW	ANGULAR COVERAGE PITCH	 HEAD.	APPROXIMATE COMPRESSION FACTORS PITCH	 HEAD.	NOMINAL BRIGHTNESS		LINE WIDTH		FILTERS	C
VDIG HUD	• Projected • Line Written • Head-up • VSD	70 lb (DVI & HUD total)	16°	60°	16°	1:6	1:6	To Pilot: 900 ft L, min., before coating of combiner At CRT: 10,000 ft L prior to coating of combiner		0.001 in		Red	
A-7A/D	• Projected • Line Written • Head-up • VSD		20°	20°	20°	1:1	1:1	Combiner Image: 1600 ft L in 10,000 ft L background CRT: 4000 ft L		.1 +.02 milrad. At 90% brightness .007 in.		Not Specified	
ILAAS HUD	• Projected • Line Written • Head-up • VSD	64 lb max.	25°	25°	Not Specified	1:1	Not Specified	At least 900 ft L, max.		1 mil radius		Red	

A.

[illegible] HEAD.	NOMINAL BRIGHTNESS	CONTRAST	RESOLUTION HORIZONTAL	VERTICAL	SPOT SIZE	LINE WIDTH	FIELD RATE INTER-LACE	FILTERS	COATINGS	PHOS-PHOR	NOTES
1:4	500 ft L	10 shades of gray in terrain avoid-ance mode		500 lines			60 cps 2:1	Micro-mesh & Red	Anti-reflec-tion	P 20	
1:5	550 ft L in 10,000 ft L background	7 distinct steps between CRT lumi-nance limits	450 lines	525 lines See Notes			60 cps 2:1	Micro-mesh & Red	Anti-reflec-tion	P 31	Resolution, Vertical: Maximum of 5% horizontal lines lost during vertical retrace.
											The information from this display is pre-sented to the pilot on the DVI by means of scan conversion. Thus, DVI character-istics are applicable. A sector scan switch is used to display TID symbols at full size on the smaller DVI.
[illegible]			350 lines	500 lines			60 cps 2:1	Micro-mesh or Pol-arized	Not Spec-ified	P 1	
NA	1500 ft L, min.		At least 460 lines at any point on display					Red	Not Spec-ified		
[illegible]	1000 ft L with 10,000 ft L background	7 shades of gray capability*, 4 shades used in con-tact analog mode Shade (% of max) Brightness Bright 93% ±5% Med. gray 50% ±10% Dark gray 20% ±10% Black 2.5% ±2.5%	500 lines	450 lines min.			60 cps 2:1	Micro-mesh & Red	Not Spec-ified	Not Spec-ified	* 10 gray shades specified for LLLTV mode.
		7 gray shades for 5 contour lines in terrain following (a/o) avoidance mode	For terrain following see Notes								Terrain Following Mode: Resolution: Minimum of 53 increments of azimuth displayed. Nominal resolution of increments: 1.5°.
[illegible]	DVST 1200 ft L	Not Specified	Not Specified	Not Specified	See Notes			Red	Anti-reflec.		Spot size: At 1000 ft L, .007 in. At 2000 ft L, .015 in.
	PPI line: 1000 ft L	(PPI, Missile TV) 6 gray shades Brightness ratio be-tween shades 1.4:1	Center: 120 1/in. Edge: 100 lines/in (Miss TV)	80 lines/in. (Missile TV)		.01 in. max. (PPI-1 E-scan)	40 cps 2:1 (Missi-le TV)				E-Scan: Elevation angle: +5° to -25°. PPI: 90° azimuth sector shown.
[illegible]	150 ft L to 1.5 ft L range with micromesh in place	Shade (% of max) Brightness Bright 100% +0% -5% Semi-bright 60% ±5% Light 34% ±4% Light gray 18% ±3% Gray 9% ±2% Dark gray 3.5% ±1% Black 0(.0001 ftL)	Not Specified	Not Specified	.030 in at max. bright-ness		Not Spec-ified	Micro-mesh & Red	Anti-reflec-tion	See Notes	Phosphor persistance of P 20 or P 31 specified.

[illegible] [illegible]	NOMINAL BRIGHTNESS		LINE WIDTH		FILTERS	COATINGS	PHOS-PHOR	NOTES
[illegible]	To Filter: 900 ft L, min., before coat-ing of combiner At CRT: 10,000 ft L prior to coating of combiner		0.001 in		Red	Combin-er: tri-chroic	P 31	Automatic Brightness Control. Refresh Rate = 50 cps.
[illegible]	Combined Image: 1600 ft L in 10,000 ft L background CRT: 6000 ft L		.1 ±.02 milrad. At 90% bright-ness .007 in.		Not Spec-ified	Combin-er: tri-chroic	P 1	Refresh Rate = 60 cps. Compression factors estimated from available information. Standby Mode Aiming Reticle: 3000 ft L, 1.4 milrad line width.
[illegible]	At least 900 ft L, max.		1 mil radian		Red		P 1	Data Update Rate: 50 cps minimum. Standby Mode Aiming Reticle: 900 ft L on a 10,000 ft L background, 1 milrad. line width at max. brightness.

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B.

CHAPTER VI - SUMMARY AND RECOMMENDATIONS

INTRODUCTION

This study has examined the major human and equipment variables related to electronic and optically generated aircraft displays. E/O displays are defined as those devices by which an image is generated electronically and presented to the observer either directly on the image generating surface or indirectly through an optical projection system. In terms of use, E/O displays have been classified as either horizontal situation displays or vertical situation displays. The latter category has been further subdivided into direct view displays and projected or head-up displays. Because of their historical importance and wide current use, cathode ray tube displays have been given primary consideration, but other techniques of image generation, such as electroluminescence, have also been treated. As used in this report, the term E/O display is restricted to those devices used by the aircraft pilot for the purposes of flight and mission control. However, the findings of this study in the areas of symbology and display characteristics may also be applied to displays used by other crew members and, in some cases, by ground operators.

The purpose of this study has been threefold:

1. To survey the research literature and current display designs to determine the extent to which E/O displays could now be standardized;

2. To provide a body of reference information which could be used to support the writing of such a standard;

3. To delineate those areas in which further research is needed before standardization could be accomplished.

Our intent has not been to write a standard for electronic and optically generated displays. Rather, we have sought to assemble and interpret the research information and other documentation upon which a standard could be based. The responsibility for developing a standard, if one is to be written at all, lies with the military services.

This chapter is a recapitulation of the major findings of the study and a summary of our recommendations in those areas where evidence from research and practical experience indicates that a regulatory document could now be written. For those areas where standardization seems desirable but not yet attainable because of insufficient or inconclusive evidence, we have outlined what additional research or investigation is needed.

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GENERAL CONCLUSIONS AND RECOMMENDATIONS

1. The available information on E/O displays and the human factors related to their design is sufficiently well developed and precise to make possible the formulation of a meaningful standard covering many equipment requirements, performance characteristics, and conditions of use.

2. Such a standard, however, cannot yet be made as complete and comprehensive as it should be. There are some areas of doubt and points of dispute which will require additional investigation and analysis to resolve. The major research needs are listed at the end of this chapter.

3. If a standard is drawn up, it should include a realistic display philosophy as well as specific values for human and equipment variables. The more important elements of this philosophy are set forth in the specific conclusions and recommendations below. (See items 1, 2, 3, 8, 9, 18, 19, 20, 25.)

4. Existing military standards and specifications relating to conventional aircraft instruments cannot be applied to E/O displays except in a limited way. Efforts to extrapolate from research findings in the area of conventional instruments have only served to underscore the uniqueness of E/O displays and the need for design requirements to be developed with the special qualities of E/O displays in mind. However, as the E/O display must be compatible with other cockpit instruments, so too must an E/O display standard be generally consistent with the body of regulatory documents now in force for the military aircrew station. The applicable existing standards and specifications are listed in Appendix A.

5. From the survey and analysis of eleven display designs now in use or proposed for use in military aircraft, it appears that there is a limited de facto agreement on some matters of information content, symbology, and display equipment characteristics. This agreement is not sufficiently wide nor sufficiently correct in all its details to constitute, in and of itself, the basis for a standard. This is to say that an E/O display standard must be more than just a synthesis of the best of current practice. It must draw upon other sources of information and experience; and, in some cases, the standard must lead rather than be led by present technology and design concepts. On the other hand, the existence of consensus on some matters suggests that it is possible to attain agreement on others.

6. The design of E/O displays and the formulation of a standard governing them must take into consideration the aircraft system as a whole. It is not enough to consider the display by itself, or even the

display with its associated sensors and data processing equipment. Attention must also be given to the performance of the aircraft, the mission requirements, and the overall role of man in the system. This suggests that an E/O display standard can never govern all aspects of design and that a standard must leave room for the display to be tailored to the specifics of the system in which it will be used.

7. In general, the design of displays for helicopters has received a disproportionately small amount of attention, and too little effort has been devoted to development of instrumentation which permits the pilot to make fullest use of the agility and freedom of rotary wing aircraft. The same appears to be true of V/STOL aircraft, although this may be more the result of the newness of this type of vehicle. Both types of aircraft tend to be limited by display concepts which are only adaptations of fixed wing aircraft displays. An E/O display standard should take into account the inherent differences among aircraft types and should avoid imposing display principles or regulations that are not appropriate to the performance characteristics of the vehicle. See research topics 1 and 8.

8. E/O displays are multiparameter displays which present a more complete and integrated analog of the flight situation than is obtainable from a grouping of several conventional instruments. For this reason a standard must give attention to the characteristics of the situation model contained in the display by specifying what is to be included and excluded, by indicating what amount of static and dynamic realism is required, and by defining the operational rules which the display must obey.

SPECIFIC CONCLUSIONS AND RECOMMENDATIONS

Specific conclusions and recommendations are grouped under the three main headings of information requirements, symbology, and display characteristics. Within each topic the findings are summarized in the order in which they were developed in Chapters III, IV, and V. The page numbers in parenthesis refer to the place in the report where these subjects are discussed.

Information Requirements

1. Apart from certain basic information requirements which are common to all aircraft, information requirements for E/O displays vary as a function of aircraft type and mission. Any standardization of E/O display content must take these differences into account by offering, in addition to a basic requirements list, a statement of the information needs peculiar to the class of aircraft and its operational use. As a minimum, the standard should distinguish among fixed wing, rotary

wing, and V/STOL aircraft. Ideally it should also specify the mission peculiar needs for attack, bomber, fighter, transport, and trainer aircraft. (pp. 22-23) See research topic 1.

2. Information requirements for special mission phases or flight situations also need to be specified. The more important of these are terrain following or avoidance, weapon delivery, formation flying or station keeping, and collision avoidance. (pp. 106-129)See research topic 2.

3. In stating information requirements, an E/O display standard must distinguish between basic display formats. That is, information requirements must be established separately for vertical situation displays and horizontal situation displays. (pp. 5-8) See also recommendation 19.

4. Information requirements for vertical situation displays are listed in Table 14 (p. 101). This list represents the basic minimum for all aircraft for the takeoff, en route, and landing portions of the mission. Where an item is appropriate only for a certain type of aircraft it is so noted. (pp. 96-100)

5. The basic information requirements for horizontal situation displays are listed in Table 15 (p. 105). Certain options and mission peculiar alternatives are also identified. (pp. 102-104)

6. Information requirements for terrain avoidance are listed in Table 16 (p. 110). Since this list was derived from our own analysis of a particular aircraft system, it should be taken more as a sample than as a statement of general applicability. (pp. 106-126)

7. Information requirements for weapon delivery are highly specialized and vary largely as a function of individual weapon or weapon system characteristics and as a function of the delivery maneuver. Weapon delivery information probably cannot be standardized except in very broad terms. The more appropriate way to handle these requirements is to incorporate them in the weapon and fire control portions of individual aircraft specifications. (pp. 127-129)

8. The data processing system which supports the E/O display should provide information about its own state and about the state of other important aircraft subsystems. As a corollary, information processing and display must be such that there is no ambiguity about the source and validity of the information signals driving display elements. (p. 34, p. 205) See also recommendation 24. See research topic 7.

Symbology

9. Coding Theory and Principles (pp. 135-141)

   a) There are several theories of information coding, but none is wholly adequate for predicting the usefulness and suitability of particular coding techniques. However, there is a large amount of reliable empirical evidence upon which to draw in constructing information codes. (p. 141) See recommendations 10 through 18.

   b) General considerations in the selection of a code are human sensitivity to coding stimuli, the user's perceptual and operational task, and compatibility with the real world situation to be encoded. (p. 141)

   c) The general criteria for evaluation of a code are the speed and accuracy of observer response. However, acceptable limits for these parameters have not been satisfactorily defined, especially in relation to operational requirements. (pp. 139-141) See research topic 10.

   d) If absolute judgments are required, the number of discriminable steps within a coding dimension is limited - between five and nine steps for most codes. If only relative judgments are required, the number of coding steps is virtually unlimited. (p. 139)

   e) Each symbol on a display must be uniquely identifiable with respect to at least one coding dimension, and preferably more than one. (p. 162) See recommendation 17.

   f) The meaning and behavior of a symbol should be consistent throughout all modes of the same display and from one display to another in the same aircraft.

10. Symbol Size (pp. 143-144)

   a) Minimum symbol size should be between 15 and 30 minutes of arc to insure visibility across a broad range of viewing conditions and for a variety of visual tasks. The dimension to which this value applies is the diameter of a circle, the side for a square, the longer side for a rectangle, and the base or height of a triangle (whichever is less). (p. 143)

   b) Size is a relatively poor coding dimension; the maximum usable number of steps is about four. (pp. 143-144)

c) If size is used as a coding dimension, the steps should be equally spaced on a logarithmic scale. (p. 144)

11. Shape Coding (pp. 144-147)

a) The most distinctive geometric shapes are the circle, rectangle, cross, and triangle (not in rank order). Squares, ellipses, and polygons are poorly discriminated. (p. 145)

b) Unique or pictorial shapes such as flag, airplane, rocket, or anchor are also good in specific situations. (p. 145)

c) Variations of a single shape should be avoided. (p. 145)

d) The discriminability of a shape tends to increase with size. Therefore, within practical limits, the more important it is to recognize a given symbol the larger it should be. (p. 147)

e) Pictorial qualities are as important as discriminability in selecting a shape for a symbol which represents a real world object. The more closely a symbol resembles its real world counterpart the more readily will it be recognized and interpreted as such. (p. 146 pp. 168-171 pp. 179-183)

f) Symbol shape may also be selected for its resemblence to other instruments or controls used in conjunction with the E/O display. (p. 147)

g) For tactical information presentations on HSDs the symbol alphabet now in use in data systems such as NTDS, ATDS, and MTDS should be adopted as standard for E/O displays. (p. 146)

h) The applicability of cartographic symbols to E/O map displays is being investigated. As a general guide, however, symbol shapes should conform insofar as possible to existing cartographic conventions. (p. 146). See research topic 11.

i) A complete standardization of symbol shapes is not possible on the basis of existing research data or current practice. Recommended shapes for some commonly used VSD and HSD symbols are given on pages 206-210. See also recommendation 25.

12. Alphanumerics (pp. 148-154)

a) For HSDs and direct view VSDs minimum alphanumeric symbol height should be 15-25 minutes of arc. The higher value should be used if emphasis is required, if the display is used in high ambient light, or if background contrast is less than 100 per cent. (pp. 152-154)

b) The width-to-height ratio of alphanumerics should be between 60 and 80 percent. The stroke-width-to-height ratio should be on the order of 1 to 8. Allowances should be made for generation techniques and for the horizontal and vertical resolution of the display system. (p. 151)

c) For raster displays the number of raster lines per symbol height must be considered. Under good viewing conditions symbol height should be 15 minutes of arc and consist of at least 10 raster lines. Under poorer conditions symbol height should be 25 minutes of arc and consist of 16 raster lines. (p. 153)

d) For raster displays the active element of the raster should be about twice the width of the inactive element. (p. 152)

e) To insure 99 per cent accuracy of reading the minimum size of characters near the edge of the raster should be about 10 per cent greater than those near the center, *i.e.*, 16.5 - 27.5 minutes of arc at the edge compared to 15-25 minutes of arc at the center. (p. 151)

f) The critical viewing angle at which inaccuracy of alphanumeric symbol reading begins to occur is between 19 and 38 degrees from a line of sight normal to the display surface. (p. 152)

g) For head-up displays a slightly larger symbol size may be required to insure good visibility against a variety of backgrounds. 30 minutes of arc is recommended, but this value should be verified by additional research. (p. 153) . See research topic 13.

h) Research evidence does not yet support the superiority of any particular symbol font for E/O displays. In the interim, the MIL-M-18012 font should be set as a goal to work toward. However, deviation is to be expected and should be tolerated so long as the designer can demonstrate that his variation still provides 98-99 per cent accuracy of reading. (pp. 151-154). See research topics 12 and 13.

13. Color (pp. 154-159)

a) Color coding is a major aid in search and recognition tasks. There is some evidence that color may also enhance legibility. (pp. 154-156)

b) The number of absolutely identifiable spectral hues is about ten (or if white is included, eleven). The maximum usable number, however, is on the order of five to eight. Present technology limits the number of discriminable hues on CRTs to between four and seven, although improvement is to be expected. (pp. 156-157)

c) There is very little evidence on the relative effectiveness of various hues for coding on E/O displays. Some experiments suggest that red is the most discriminable. Yellow and magenta also appear to be effective colors. (pp. 157-159)

d) A standard color code for E/O displays cannot be specified on the basis of existing experimental evidence. (p. 158). See research topics 14 and 15.

14. Human capacity to make absolute or relative judgments of velocity and acceleration is poor. Therefore, motion coding is not recommended for use on E/O displays. (pp. 159-160)

15. Flash (pp. 160-161)

a) Flash coding is not recommended for E/O displays except as an attention-getting device, and even for this purpose it should be used sparingly. (p. 161)

b) Flash rates should be between 1 - 4 cps, with the on and off portions of the cycle about equal. (p. 160)

c) Since there appears to be a stereotypic association between flashing and urgency and since higher flash rates tend to be more conspicuous and to promote prompter response, flash rate should be selected with the required speed of perception and response in mind.

16. Brightness (pp. 161-162)

a) Brightness coding (*i.e.*, contrasting shades of gray) is used extensively on raster displays, where it serves as an effective substitute for color coding. At the present state of CRT technology seven to ten distinct brightness levels can be attained throughout a range of ambient lighting conditions. (p. 161 pp. 238-240) See also recommendation 28.

b) For line written displays brightness coding is of limited usefulness, two or three steps being the practical limit. If used, it is recommended that the higher brightness level be reserved for items of primary interest and the lower level(s) for background or supplementary information. (p. 161)

c) Brightness coding is not recommended for head-up displays because of the poor contrast effects of low brightness levels against a high ambient light background.

17. Compound Codes (pp. 162-163)

a) Compound codes are useful for incorporating more than one dimension of information within a single symbol. Compound codes save space but at the expense of increased response time and error probability. (p. 162)

b) Each constituent of the compound code must be readable separately without confusion. (p. 162)

c) Only one coding dimension should be used for each dimension of information. (p. 162)

d) One coding dimension should not be used for more than one dimension of information. (p. 162)

e) Compound codes tend to decrease the number of discriminable steps within each of the constituent coding dimensions. Therefore, it is wise to use fewer than the maximum discriminable number of steps for each of the dimensions in a compound code. (p. 163)

18. Code Compatibility (pp. 163-165)

a) Man's information handling capacity varies by a factor of as much as 2 or 3 as a function of code compatibility. (p. 163)

b) Codes are more easily interpreted when qualitative information is encoded qualitatively and quantitative information is encoded quantitatively. (p. 164)

c) For pictorial displays codes should be selected so as to represent a familiar approximation of the real world situation. The code should comply with familiar stereotypic meanings associated with each symbol, and it should provide as direct an association as possible between the symbol and the thing represented. (p. 164)

d) Apart from purely pictorial representations, there are very few stereotypic associations between coding dimensions and items of information. The more significant of these are listed on page 165.

19. Reference System and Display Dynamics (pp. 167-185)

a) E/O displays should be spatially ordered or structured so that the coordinates of the display system have a natural and direct relationship to the structure of the external world as perceived from the aircraft and to the coordinates of the aircraft control

system. The two most suitable display formats are the vertical situation display, which represents a projection of the aircraft situation on a vertical plane ahead of the aircraft, and the horizontal situation display, which is a projection of the aircraft situation on a horizontal plane beneath the aircraft. These should be adopted as standard formats for E/O displays. (pp. 167-168)

b) As a rationale for assigning information to the VSD or the HSD, it is generally recommended that information relating to attitude, steering, flight path, and other short term aircraft response characteristics be presented on the VSD, while information relating to geographic orientation and position, the air situation, and other long term response characteristics be allocated to the HSD. (pp. 168-169)

c) Not all the requisite parameters of flight can be integrated into the spatial analogs of the VSD and the HSD. For these items it is recommended that certain conventions of format and grouping be adopted. (p. 170) See recommendation 20.

d) The aim in E/O display design should be creation of a display which provides a veridical view of the flight situation. This suggests the need for both pictorial realism and fidelity to the dynamic aspects of flight. (pp. 171-178)

e) All of the E/O displays surveyed and all conventional attitude indicators now in military use are inside-out, fly-to indicators. The preponderance of experimental evidence, however, favors the outside-in and fly-from concepts. Before choosing one or the other we recommend that the military services review the evidence on both sides and conduct additional experiments. (pp. 172-179) See research topic 16.

f) For HSDs the issue of inside-out vs outside-in is not so critical or so sharply drawn. For practical reasons the inside-out (moving map) display seems preferable, and we recommend its adoption as standard for HSDs. We further recommend that HSDs include a feature which permits the display to be rotated to a north-up or heading-up orientation to facilitate the reading of alphanumerics and other cartographic symbols. (pp. 178-179)

g) The issue of the contact analog vs other less pictorial or literal displays has not been fully explored, and experimentation is still in progress. On the basis of preliminary findings it appears that the contact analog is not wholly adequate for precise flight control and that it must be supplemented with certain non-pictorial or quantitative indications. We recommend that an E/O display standard permit the designer some latitude with

respect to the literalness of the display and the amount of supplementary quantitative symbology to be added. (pp. 179-185) See research topics 18 and 19.

20. Format and Placement (pp. 186-195)

a) On the VSD the display center is the most important reference point. Insofar as possible this area should be kept free of other symbology so as not to interfere with the display of attitude and steering information. (p. 187)

b) The display center on the VSD should be marked with a symbol which is clearly visible both day and night.

c) Brightness or color codes are recommended as methods of distinguishing between the aircraft symbol on the HSD and other symbols which happen to be coincident with it. (p. 161)

d) Symbols should not be allowed to overlap each other or to cross in their paths of movement unless the rules of the spatial analog require them to do so. (p. 187)

e) The following conventions of format are recommended for indicators which cannot be integrated into the VSD reference system. (pp. 188-191)

Altitude - vertically oriented on the right side of the display.

Airspeed - vertically oriented on the left side of the display.

Roll Scale - horizontally oriented at the top of the display.

Vertical Velocity - vertically oriented on the right side of the display.

Heading - horizontally oriented on the bottom of the display or placed along the horizon and major pitch lines.

Angle of Attack - vertically oriented on the left side of the display.

Discretes - no standard location. As a general rule, discretes should be placed so that they neither obscure, nor are obscured by, other symbols. If related in meaning to some other display symbol, the discrete should be located near it.

f) As general guides to format and placement it is recommended that symbols be grouped according to patterns of use, relationships between items of information, and importance. (p. 192)

g) Display dynamics must also be considered in working out format and placement. It is important that symbol position and movement be compatible with the dynamics of the spatial analog. (p. 192)

h) There is no common agreement about what constitutes clutter or how it is to be avoided. Some of the factors contributing to clutter are symbol density, overlap and interference, irrelevancy of information, lack of consistency either internally or in relation to the real world, and lack of an overall pattern or integrating structure. As general rules for the avoidance of clutter, symbols should be few in number, their movement should be simple, and symbols should not obscure each other or real world elements. The latter point is particularly important for head-up displays. Techniques such as blanking of low priority information, protective windows or zones around important symbols, and use of symbol size differentials should be considered. (pp. 193-195)

21. Null Symbols (pp. 197-199)

a) The morphology and dynamics of null symbols are intimately connected with matters of machine dynamics and human transfer functions. Standardization in this area seems neither possible nor desirable. (p. 197)

b) An E/O display standard should permit freedom of choice in the characteristics of data inputs to null symbols, *i.e.* techniques such as smoothing, filtering, and quickening should be permitted. (p. 198)

c) The optimum scaling or sensitivity of null symbols is, likewise, not subject to standardization since it depends upon the response characteristics of the individual aircraft system and the accuracy requirements of the mission. As general rules, however, there should not be too great a disparity between horizontal and vertical scale factors on the display; the scale factors should be uniform for all elements expressed in the basic reference system coordinates; and the scale factor should not vary from one mission phase to another or between display modes. (p. 198)

d) Strobing of symbols should be avoided. A method for calculating the point at which strobing will occur is given on page 199.

22. Scales and Tapes (pp. 200-203)

   a) Experimental evidence does not indicate a clear superiority of either the fixed scale-moving pointer or the moving scale-fixed pointer. Each has advantages over the other in certain situations. An E/O display standard should permit either to be used. (pp. 200-201)

   b) Scales and tapes for E/O displays should conform to the established principles of good scale design. A summary of these principles is given on page 201.

   c) The triangle, the V, and the bar are recommended as the most suitable shapes for pointers on E/O displays. (p. 201)

   d) The arrangement of values on a scale should conform to the rule that up, right, or clockwise means increase, and the opposite directions mean decrease. The only possible exception is the airspeed scale which requires further investigation before the proper directional sense can be established. (pp. 202-203) See research topic 24.

   e) Scales located on the perimeter of E/O displays and expressing quantities not directly related to the display coordinate system should be roll-stabilized, *i.e.* they should not respond to aircraft roll. (p. 202)

   f) Scales located at the edge of the field of view on head-up displays should be arranged so that the pointer is on the inside, *i.e* toward the center of the display, and the numerals on the outside. (p. 202)

   g) The sensitivity of a scale should be matched with the accuracy of the data sensing and processing equipment which drives it. (p. 202)

   h) All units of measure for scale presentations should be in conformance with MS 33636. (p. 275)

23. Digital Callouts (p. 203)

   a) Digital indicators should be used for setting tasks, where a specific value must be chosen or a specific input made, or for readout of quantitative indications which are stable or change very slowly. (p. 203)

   b) Digital indicators should not be used for tracking tasks or for readout of rapidly changing values. (p. 203)

24. Discretes (pp. 204-205)

a) Shape coding is useful for encoding discrete information. The shape should be either pictorial or have a stereotypic association with the information. (p. 204)

b) Color, shade, and flash coding are best used as generic rather than specific indicators or as supplements to other codes. (p. 204)

c) If alphanumerics are used, all abbreviations should conform to MIL-STD-783 and the ANA-261 bulletin of abbreviations. (p.205)

d) As a tentative recommendation, we suggest that the presentation of discrete indicators on VSDs be limited to emergency items, a master warning indicator, and a master caution indicator. (p. 205) See recommendation 8 and research topic 25.

25. Recommended shapes for certain commonly used E/O display symbols are discussed on pages 206-210. The recommendation is <u>not</u> that these are the only shapes which may be used for the specified purposes; but that if a symbol of the indicated shape is used, it should have the meaning we have assigned to it. We recommend that standardization not proceed too far or too rapidly in this area since the available experimental evidence is not conclusive and since there is a danger of imposing unwarranted restrictions on future display designs.

<u>Display Characteristics</u>

26. Night Vision (pp. 213-219)

a) Red filters for E/O displays should be used where maximum dark adaptation is necessary. (pp. 213-219)

b) Cockpits should be uniformly illuminated to avoid hot spots from E/O displays or other light sources, which may jointly or individually destroy dark adaptation. (p. 214)

c) For maximum dark adaptation light intensity is more important than color. Display luminance should be continuously adjustable from 0.02 to 0.1 ft L. Table 19, page 215, contains recommended values for various conditions of use.

d) E/O displays should provide adequate contrast under low as well as high ambient lighting conditions. This includes symbols painted or inscribed on the display surface as well as electronically generated symbols. Additional research is needed to define adequate contrast in quantitative terms. (pp. 216-217) See research topics 26 and 28.

e) An E/O display standard should avoid terms such as "protect dark adaptation", "clearly visible", or "adequate contrast" unless quantitative definitions are provided or unless a demonstration test is provided for. (p. 218) See research topics 28 and 29.

f) A systems approach should be taken to cockpit and E/O display lighting. Lighting controls and intensity ranges should be compatible with mission needs. The pilot should have an efficient method for determining and setting appropriate light levels. (p. 218)

27. Day Vision (pp. 219-225)

a) 10,000 ft-L should be adopted as the standard extreme sky luminance (i.e., brightness) condition for evaluating the adequacy of head up display symbol luminance. (p. 220)

b) An incident light source of 10,000 ft-C illuminance is recommended as the standard for evaluating the resistance of direct view displays to contrast washout. The color temperature of the light source is not critical; a broad spectrum white at about 5,000 to 6,000 degrees Kelvin is adequate. For evaluation purposes the incident light source should be positioned in accordance with cockpit geometry and on the outside of the actual or simulated aircraft canopy. (p. 225)

c) A demonstration test of display visibility under day and night lighting conditions should be provided for in an E/O display standard, or at least in the display procurement specification. This recommendation is intended primarily for prototype equipment and new aircraft applications. As a backlog of data on earlier designs accumulates, the need for extensive mock-up testing will diminish. (pp. 223-225)

d) Specifications should be made on the characteristics of the photometers used for taking light measurements and on the procedures for assuring their accuracy. The use of two different photometers is desirable.

28. Luminance and Contrast (pp. 226-240)

a) For daytime raster display use, display contrast minimums should be specified rather than display luminance minimums, since contrast is by far the dominant consideration.

b) Specific head down raster display contrast minimums should be related to a number of display variables, *e.g.*, symbol size, acuity task, and symbol luminance. These values are not yet

firmly established for field use applications. For guidance, 100 per cent contrast is deemed to be acceptable for many E/O display uses.

c) Radar displays may require as much as 250 per cent contrast. (p. 235)

d) For nighttime raster display viewing Table 19, page 215, contains recommended luminance values for various conditions of use.

e) Head-up display luminance minimums depend on whether or not a trichroic combiner coating is used. For uncoated combiners, reflected symbol luminance on the order of 1800 to 3500 ft L is estimated to be necessary for comfortable viewing against a 10,000 ft L sky background. With a trichroic coating these values may be relaxed to 900 to 1000 ft L. (pp. 231-233)

f) The anticipated background(s) against which head-up display symbols will be viewed in operational use must be considered in establishing luminance requirements and in specifying phosphor color and trichroic coating characteristics.

g) We recommend that a standard method for expressing contrast be adopted to foster common understanding. A formula which has wide currency is suggested on page 235.

h) The literature does not adequately indicate luminance and contrast minimums for line written head-down displays. See research topic 33.

i) EL display contrast requirements should not be the same as for those CRT displays which are used for similar purposes.

29. Filters (pp. 241-247)

a) A number of devices and techniques can be used to protect direct view display contrast in high ambient light. Two of the most widely used are the micromesh filter and the circular polarized filter. An E/O display standard should permit either of these to be used. The employment of other methods to protect against washout should not be excluded, so long as it can be demonstrated that they yield at least comparable results. (pp. 241-247)

b) Antireflectance coatings should be used on all significant reflecting surfaces of E/O displays in conformance with the general practice in military aircraft.

c) Aviation red filters are recommended for night use on E/O displays when maximum dark adaptation is desirable. See also recommendation 26.

d) An E/O display standard should permit the use of trichroic coatings (color separation filters) for head-up display combiners. (pp. 246-247)

30. Flicker (pp. 251-254)

a) For direct view raster displays a repetition rate of at least 60 cps is recommended. (p. 253)

b) For direct view line written displays and for head-up displays a lower writing frequency is believed acceptable. For displays which use P1 phosphor 50 cps is acceptable as a minimum repetition (refresh) rate. For other phosphors 45-55 cps may be suitable. (pp. 253-254)

c) A distinction should be made between flicker threshold and the point at which flicker becomes distracting or deleterious to performance, i.e. the point at which flicker becomes objectionable. Quantitative definition of objectionable flicker is needed. (p. 253)

31. Resolution (pp. 255-266)

a) Resolution requirements for E/O displays cannot be specified in isolation because they depend on a number of other factors - display contrast, screen size, symbol size, viewing distance, sensor resolution, and so on. The following recommendations are offered for general guidance.

b) The entire sensor/display system should be considered in establishing resolution requirements. If complete system data are not available, a rule of thumb to apply is that display resolution should be twice that of the most stringent sensor resolution requirement. (p. 260 ,p. 266)

c) If sensor data are not available but mission requirements are known, display resolution should be based on the most stringent mission or task requirement. (p. 266)

d) If neither of the above seem appropriate and a TV mode is called for on the display, display resolution requirements can be based on the level of resolution required of the video system for the observer to perform a specified task. (p. 266)

e) For raster displays which provide only stylized or synthetically generated symbols, 500 raster lines is generally accepted as a suitable resolution. If the addition of multisensor capability and LLLTV is anticipated, resolution as high as 1000 lines may be required. (p. 257, p. 266)

f) For raster displays a minimum of 10-16 raster lines per symbol height is required for a symbol of minimum size (i.e., 15-25 minutes of arc). (p. 259) See also recommendation 12c.

g) For line written head-up displays, line widths should be approximately 3 minutes of arc. For direct view displays this is equivalent to 0.024 inches at a viewing distance of 28 inches. (p. 265)

h) To relate resolution requirements to screen size and other basic display parameters, charts such as those provided in Whitham (1965) may be used. (p. 260)

i) A standard technique for measuring display resolution should be adopted. Three of the most frequently used are described on pages 261-262)

32. Color (pp. 267-268)

a) The selection of a phosphor for monochromatic displays depends upon factors such as persistence, flicker characteristics, target detectability, and burn resistance. Phosphor color should not be standardized, but left to the discretion of the display designer. (p. 254, p. 268)

b) Multicolor displays are not yet practical for airborne applications, and color tube technology is still in an emerging state. Standardization in this area would be premature. (p. 268) See research topics 14 and 15.

33. Optics and Field of View (pp. 269-272)

a) The relation between field of view for head-up displays and performance requirements has not been adequately clarified by research. Considerably more work must be done before reasonable minimums can be established. (p. 270) See research topic 38.

b) For the purposes of standardization a distinction must be made between binocular and monocular fields of view and between instantaneous and total fields of view.

c) At the present state of technology an instantaneous binocular lateral field of view of 15-20 degrees is attainable with the gunsight and extended pupil optical systems used in head-up displays. While there is no assurance that such a field of view is adequate, a display which offers less than this ought not to be accepted. (p. 271)

d) Vertical field of view is related to over-the-nose vision requirements for such maneuvers as landing, terrain avoidance, or weapon delivery. These are largely peculiar to the aircraft in which the head-up display is installed and, therefore, are not subject to across-the-board standardization. In general, sufficient vertical field of view should be provided so that symbol placement and viewability are compatible with cockpit geometry, range o eat movement, aircraft angle of attack, and the 5th to 95 percentile pilots' measurements. (p. 271)

e) An E/O display standard should also make provisions concerning the tolerance for binocular disparity, collimation error, and the effects of head movement; but these matters must await the results of investigations now in progress. (p. 271)

34. Standards of Measurement (pp. 273-275)

a) The angle subtended at the eye is recommended as the unit of measurement for symbol size and field of view on both projected and direct view displays. (pp. 273-274)

b) Eye position (in cockpit coordinates) and viewing distance should also be specified. Eye position should be established in accordance with existing cockpit geometry and vision standards and specifications. (See Appendix A.) For panel mounted direct view displays in fixed wing aircraft, a viewing distance of 28 inches should be standardized. For similar displays in helicopters a viewing distance of 18-20 inches should be used. (p. 274)

c) Display luminance should be expressed in foot lamberts or millilamberts. Illuminance should be expressed in foot candles. (p. 274)

d) In specifying symbol accuracy, distinctions must be made between static positional accuracy, size accuracy, and dynamic accuracy. Accuracy requirements should be guided by the use of the symbol on the display. (pp. 274-275)

e) MS 33636 should be used as a guide for all flight and propulsion parameters expressed on the display in quantitative units. (p. 275) See also recommendation 22h.

RESEARCH NEEDS

The foregoing conclusions and recommendations, numerous as they are, constitute only the first step toward formulation of an E/O display standard. There is a wealth of research literature and other documentation relating to display design, but there are still many areas in which we know very little of practical consequence. The effects of many human and equipment variables have been only partially investigated, and the interactions between some of them have scarcely been explored. Technology is envolving rapidly; but if we are to make best use of these innovations, we must keep pace in research on the human factors in display design and on the ways in which these devices can be welded into effective military systems.

This section lists in summary form the major research needs which have been identified by our review of the literature and survey of present display designs. No attempt has been made to knit these research topics into an integrated and comprehensive program of research. Rather, they are to be taken as specific suggestions of topics to be incorporated into the overall JANAIR program. They also serve to identify for any group concerned with standardization the information still needed to support the writing of a meaningful and realistic regulatory document.

As with the specific conclusions and recommendations, the suggested topics for research have been grouped under the headings of information requirements, symbology, and display characteristics. The items marked with an asterisk (*) are those which, in our estimation, should be given high priority.

Information Requirements

* 1. The tendency has been to develop information requirements for displays as part of the development process for the particular aircraft in which they are to be installed. Validation of these requirements for each aircraft by experimentation prior to operational deployment is simply not feasible, and the process is generally wasteful of time and resources. Notable exceptions to this trend were the IHAS and ILAAS programs in which an attempt was made to formulate display requirements generically. There is a need for further analytic studies to develop general models of information requirements for other aircraft types and missions. These models should be based upon the performance characteristics of the aircraft class, service experience with versions in operational use, anticipated developmental trends, and future mission needs.

* 2. As a parallel effort, analytic studies are needed to establish information requirements for special mission phases or flight situations. Among these are terrain avoidance or following, weapon delivery, formation flying or station keeping, and collision avoidance.

3. E/O displays offer exceptional possibilities for the integration of information and for presentation of a much more complete and realistic picture of the total flight situation than is possible with conventional instruments. Studies are needed to establish the appropriate degree of automation in data processing systems which support E/O displays. Also to be considered are the information requirements associated with monitoring and override of automated control systems.

4. Despite important advances, all-weather operation - especially all-weather landing - is not yet a reality. In part this is a problem of sensors and guidance equipment, but there is also a lack of knowledge about the pilot's information needs in the blind landing situation. That is, most IFR systems are designed to bring the aircraft to a minimum decision altitude or breakout point, after which the landing is completed visually. This is vastly different from giving the pilot the information and the display he needs to fly blind to touchdown with all the confidence and assurance of safety that he has VFR.

5. For all their capacity, it would be stretching the limits of E/O displays to propose that they contain all the information pertaining to the flight situation and aircraft control. Studies should be conducted to develop a scheme for distribution of information between E/O displays and conventional, special purpose instruments and to define the roles of each with respect to pilot control functions.

6. As a continuation of the foregoing, the roles of various types of E/O displays need to be defined. Some aircraft now contain both a head-up display and a direct view VSD, and it is not hard to foresee that future aircraft may also have a HSD, a multisensor display, and a multiparameter display of system status and performance. There is a need to define a scheme of use for the several displays in relation to mission requirements, to determine how best to allocate information among them, and to establish the requirements for redundancy and backup.

* 7. Studies should be made of the methods for displaying warning and system status information on E/O displays. This includes not only monitoring of other aircraft subsystems but also self-monitoring and self-test of the display itself. Also to be investigated are displays which provide information about alternative courses of corrective action and allow the pilot to choose between manual and automatic corrections. In its most general form, this problem is one of providing the pilot with information which will assist him in his role of system manager.

* 8. The special properties of helicopters and V/STOL aircraft do not seem to have received sufficient attention. Studies should be devoted to developing display concepts and information presentations which are truly suited to the performance capabilities of these types of vehicle.

Symbology

9. The principles of information coding as they apply to E/O displays have not been fully developed. In part this requires an extension and refinement of theoretical work about coding in general. However, there is also a need for experimentation with specific coding techniques. This is not a call for additional investigation of the discriminability of particular coding dimensions. The aim should be, instead, to find optimum coding solutions for E/O display problems, *e.g.* a method for coding range on contact analog displays, how to integrate altitude and speed into the VSD format, and ways to encode command and status information for a particular flight variable.

10. Speed and accuracy of reading are the most frequently used criteria for evaluation of a code. Very little has been done, however, to relate these factors to mission performance and realistic operational situations. It is not enough to know that one code can be read faster or with fewer errors than another. One must also set these considerations against perceptual or task requirements and the consequences in performance or crew safety.

* 11. There is reason to doubt the suitability for E/O displays of certain cartographic conventions and symbols now used on printed maps. Investigations should be conducted to determine a symbology for projected maps which is not only optimum in readability but compatible with printed map symbology.

12. Studies should be undertaken to develop an alphanumeric font suitable for direct view raster displays. The MIL-M-18012 font has been suggested in this study as a goal to work toward, but there is no clear evidence to indicate that it is superior to other fonts which might be easier to generate electronically. Consideration should be given not only to the variety of environmental conditions which obtain for E/O displays but also to the manner in which alphanumerics are used. That is, alphanumerics should be tested in configurations typical of E/O displays and for realistic operational purposes.

13. Similar studies should be conducted for alphanumerics on line written displays, particularly head-up displays. Of special interest are symbol characteristics such as size, stroke-width-to-height ratio, and distinctiveness of shape against a variety of real world background. Ideally, the fonts for raster and line written displays should be similar; but readability, suitability for the display medium, and economy of generation are probably the more important considerations.

* 14. It is desirable to establish the relative discriminability of various colors which can be generated on CRT displays. Consideration should be given to high and low ambient light conditions and to the effects of the use of red lighting in surrounding parts of the cockpit.

* 15. Efforts should be made to establish a rationale for color coding E/O displays. A single general scheme may not be attainable, and it seems likely that different, but compatible, schemes will have to be developed for direct view VSDs, head-up displays, and map displays. It is also advisable to study the possibility of reserving certain colors for certain classes of information, *e.g.* command and status or caution and warning.

16. The issue of an inside-out vs. outside-in reference system for command and altitude deserves further investigation before setting a standard for E/O displays. Simulator and flight trials are needed to obtain comparative evaluations of performance with the two types of displays. The aim should not be to establish that one or the other is workable or even suitable for a given purpose, but which is better.

* 17. As a test case of the viability of the outside-in display we have suggested that head-up display embodying this principle be subjected to simulator and flight experiments. (See pages 178 and 184)

18. The kinalog and frequency separation concepts discussed on pages 171 and 182 should be studies as possible solutions to the inside-out/outside-in dilemma.

19. Experimentation with the contact analog display concept should be continued, with particular emphasis on determining the adequacy of such displays for specific operational missions and the need for supplementary quantitative or symbolic indices. The general aim should be to establish the optimum mixture of pictorial and symbolic indications on direct view and head-up displays for specific mission-related flight tasks.

* 20. Studies should be made of the transfer effects between E/O displays used together or sequentially by the pilot. Of particular concern is establishing the degree of compatibility required between direct view VSDs and head-up displays with respect to symbology, format, and dynamics. It would also be useful to have data on interactions between VSDs and HSDs or other types of E/O displays as well as between E/O displays and conventional instruments used in association with them.

21. There is some experimental evidence that the detectability of a target or symbol varies as a function of the area of the display in which it appears. Investigation of this point should be pursued to determine its implications for E/O display format, especially the placement of symbols which are not integrated into the spatial analog of the display.

22. Studies are needed to identify the factors contributing to display clutter and measures for preventing it. The trend in E/O displays seems to be toward including more and more information, which produces more complex formats and "busier" displays. A definition of rules and limits would be of great help.

23. The principles of scale design as they apply to E/O displays have not been fully worked out. Attention should be given to such details of symbol design as pointer shape, size of scale graduation marks, and spacing of scale elements. Of greater importance, however, is research to determine the appropriate type of scale for specific E/O display uses and to develop new scale designs which overcome the advantages inherent in mechanical devices.

24. The appropriate directional sense for vertically oriented airspeed scales is still a moot point. Experiments to resolve the question would be worthwhile.

* 25. E/O displays have almost unlimited capability for the presentation of discrete indicators of system status or mission events. Studies are needed to determine the kind and amount of information which should be displayed and the form of presentation.

Display Characteristics

26. The problems of night vision will require both empirical and subjective data collection. Pilots should be queried on the need for dark adaptation and better lighting control for various types of aircraft in various missions. They should also be asked about current practices for controlling pre-exposure to light prior to night missions. As a subsequent effort pilot comments should be related to photometric measurements of such variables as canopy glare, indicator lamps, map lighting and so on. Guidelines might then be established to evaluate lighting control methods, to generalize about missions, and to identify special problems.

27. Trichroic coating transmission has not been adequately investigated in relation to night vision problems. Head-up display coatings ought not to seriously degrade such performance as night carrier landing or detection of other aircraft; but it may be necessary to make a tradeoff between contrast enhancement for day vision and degradation effects at night.

* 28. We have found that there is a host of problems related to display characteristics as they affect performance. Display contrast, resolution, noise, vibration and other factors must be investigated in both nighttime and daytime ambient environments. Tradeoff factors need to be identified in relation to performance. Empirical research evidence

is not available, and without it comprehensive, viable standards and specifications cannot be written.

* 29. A general research program to define the required visual characteristics of displays should include provisions for collecting supporting photometric and lighting data. We have mentioned this in regard to nighttime cockpit lighting. The data are even more sorely needed for high ambient light conditions. Photometric data on various cockpit configurations and canopy thicknesses should be collected, compared and summarized. Similar data on noise, vibration, and unusual visual effects (*e.g.*, rotor blade shadows) should be related to types of aircraft. This kind of data base could then be used for simulation purposes in relating display characteristics to performance.

30. Either estimations of the environment for a given display or a specification of the actual environment would be useful for demonstration test purposes. Once sufficient man-display performance data are known, or even on the basis of estimated values, display manufacturers should be required to submit new display designs to some type of empirical test. Even a relatively straightforward subjective verification that a display is usable under worst case operating conditions would be better than no formal check at all. As more data are gathered from experiments, test criteria could be more objectively defined.

31. In support of demonstrations and experiments, specifications are needed to assure that the photometric equipment for taking light measurements is properly used. Such factors as calibration frequency, known light source checks, spectral response, and aperture size should be considered.

* 32. In evolutionary cycles, simulation is recommended to help evaluate the results of independent laboratory experiments. One of the problems here is that there are many variables which can have both mixed and independent effects on performance. Trying to optimize display contrast, for instance, may not only be related to vibration, fatigue, resolution, target size, and luminance level; but also to a variety of contrast relationships in the televised real world picture. How does target contrast relate to various contrast relationships among types of trees? We generally find that many of the system equipment characteristics and transfer functions can be specified so that a given result obtains. However, this does not improve matters much if the results cannot be related to improvement in human performance.

33. In addition to establishing display characteristics and human performance relationships, simulation can be used to test the merits of types of displays and display concepts. The suitability of EL and line written displays, as opposed to raster types, or perhaps combinations of these could be tested across a variety of flight performance problems. Various measures of aircraft control could be used to determine how well the pilot responds with one or the other display, given varied environmental conditions, scale factors, and display dynamics.

34. The work of Clauer (1966), relating contrast from the observer's viewpoint to an objective method for specifying sensor/display system modulation transfer, should be continued. So, too, should the work of Pfahnl (1961) which relates phosphor burn at various intensity levels to CRT life. Such data are needed to evaluate reliability tradeoffs, particularly those affecting trichroic coating transmission requirements for head-up displays.

35. The entire area of display filters and contrast enhancement technique needs to be upgraded. Hole arrangement and spacing on micromesh filters, combinations of filters, the use of dark phosphors, halation suppression, antireflectance coatings, and fiber optics faceplates should be evaluated in terms of potential display improvement. The trichroic coating mentioned above might be useful as an internal filter for the control of direct sunlight which can enter a collimating lens system. In addition we recommend that trichroic coatings be tested against water or vegetation backgrounds. Evidence to date relates only to their use against a bright sky.

36. An acceptable resolution measurement technique should be specified for both raster and line written displays. Agreement among display suppliers, aircraft contractors, and military evaluation groups should be reached concerning the most appropriate technique to use.

37. Color techniques for E/O display applications should be investigated. Such factors as cost, weight, reliability, and luminance degradation can be evaluated against actual performance improvements to be gained via this method. One of the traditional problems in using color has been the loss of luminance. It is not clear, however, that this is as severe a problem as might be assumed. Not only are the high CRT output levels which are sometimes specified for avionics displays suspect of overdesign, but the added factor of color contrast improvements has not been evaluated. In addition, improvements in color generation techniques should be monitored to determine progress in the field.

* 38. A considerable amount of work still needs to be done in the area of optics and field of view. Comparative studies would be helpful between the extended pupil and gunsight optical systems. Distortion in both types should be related to windshield distortion, with a parallel effort to assess potential impact on real world tasks. More data are needed to evaluate field of view requirements for various aircraft types and missions. Nor, is the question of head down display field of view settled. For certain problems related to television imagery there is recent evidence that display size alone is an important factor in detection and recognition task performance. Display sizes on the order of 10 to 14 inches have been mentioned as a requirement. This evidence should be evaluated in terms of specific aircraft types, missions, and tasks; and the results related to human performance measurements.

APPENDIX A

APPLICABLE STANDARDS AND SPECIFICATIONS

Listed below are military standards and specifications which relate to electronic and optically generated displays. Some are quite broad in scope and have only general applicability to the topics discussed in this study. Others, although specific and pertinent, deal only with one aspect of E/O display design. Quite a few are concerned with standard instruments and, therefore, could not be applied to E/O displays without some qualification or modification. Nevertheless, all do bear in some way on the matter of E/O display design and provide useful guidance. In presenting this list we do not mean to imply that an E/O display standard should be merely a composite of those cited below. Rather, we wish to indicate the scope and content of relevant standards now in force and to suggest the need for compatibility between the provisions of any future E/O display standard and those of existing regulatory documents.

The standards and specifications are listed under each major topic by number and subject. Exact titles are not always given since they tend to be long and inverted statements which, in many cases, are not indicative of the relationship of the particular document to the subject of E/O displays.

Avionics

MIL-STD-454	General requirements for electronic equipment
MIL-E-5400	General specification for aircraft electronic equipment
MIL-R-23094	General specification for reliability of avionic equipment
MIL-S-23603	General specification for system readiness and maintainability of avionic equipment
MIL-T-23103	General specification for thermal performance evaluation of avionic equipment

Displays

MIL-STD-411	Aircrew station signals
MIL-STD-783	Nomenclature and abbreviations in aircrew stations

Displays (Cont'd.)

MIL-STD-884	Electrically or optically generated displays (USAF only)
MIL-I-27193	Attitude indicator
MIL-M-18012	Markings and alphanumerics for aircrew station displays
MIL-S-38039	Illuminated caution, warning, and advisory indicators.
MS-28041	Rate of turn indicators
MS-33558	Alphanumerics
MS-33585	Design of pointers
MS-33636	Units of measure
ANA-261	Bulletin of abbreviations
ASCC-Air Std-10/2	Units of measure (an international agreement which incorporates the provisions of MS-33636)
ASCC-Air Std-10/16	Abbreviations and definitions of flight control terms (an international agreement which incorporates the provisions of ANA-261)

Geometry and Vision

MIL-STD-203	Location and actuation of controls for fixed wing aircraft
MIL-STD-228	Aircrew station geometry (proposed)
MIL-STD-250	Location and actuation of controls for helicopters
MIL-STD-850	Aircrew station vision requirements
MS-25497	Basic pilot flight instruments for helicopters
MS-28112	Basic instrument arrangement for fixed wing aircraft (Navy only)

Geometry and Vision (Cont'd.)

MS-33572	Basic instrument arrangement for helicopters (Navy only)
MS-33573	Clearance dimensions for cockpit of fixed wing aircraft
MS-33574	Basic cockpit dimensions for fixed wing aircraft (stick controlled)
MS-33575	Basic cockpit dimensions for helicopters (stick controlled)
MS-33576	Basic cockpit dimensions for fixed wing aircraft (wheel controlled)
MS-33634	Engine instrument arrangement
MS-33635	Standard flight instrument arrangement
MS-33785	Basic instrument arrangement for fixed wing and rotary wing aircraft (Proposed - Air Force and Army only)

Human Factors

MIL-STD-721	Definition of terms for effectiveness (Human Factors)
MIL-STD 803	Human engineering design criteria for aerospace vehicles
MIL-STD-1472	Human engineering design criteria for military systems, equipment, and facilities
MIL-H-22174	Human factors data for aircraft and missile systems
MIL-H-27894	Human engineering requirements for aerospace systems and equipment
MIL-H-46855	Human engineering requirements for military systems, equipment and facilities
MIL-H-81444	Human factors engineering systems analysis data

Human Factors (Cont'd.)

AFSCM 80-1 Vol I	Handbook of instructions for aircraft designers (Vol. I - Piloted Aircraft)
AFSCM 80-3	Handbook of instructions for aerospace personnel subsystem designers
AMCR 70-1	Human factors
ABC-STD 10/38	Principles of information presentation (an international agreement)

Lighting

MIL-C-8779	Aircraft interior colors
MIL-C-25050	General requirements for colors of aeronautical lights
MIL-L-5057	Individual instrument light (red and white)
MIL-L-5667	Instrument panel lighting
MIL-L-18276	Aircraft interior lighting
MIL-L-23817	Electroluminescent panels
MIL-L-25467	Integrally lighted instruments
MIL-L-27160	Integrally lighted instruments (white)
MIL-P-7788	Integrally illuminated plastic panels
FED-STD-3	Colors for aeronautical lighting

Miscellaneous

MIL-STD-143	Order of precedence for selection of specifications and standards
MIL-STD-795	Colors
MIL-STD-1241	Optical terms and definitions
MIL-C-6781	Aircraft control panels
MIL-C-14806	Anti-reflection coating of glass optical elements

Miscellaneous (Cont'd.)

MIL-I-8677	Installation of armament control systems in Naval aircraft (includes optical system requirements, boresighting, and determination of the ADL)
MIL-I-18373	Installation of aircraft instruments and navigation equipment
MIL-M-8650	Mock-ups
MIL-S-8048	Preparation of specifications for aeronautical weapon systems
MIL-S-26634	Preparation of specifications for weapon system and support system mock-ups
MIL-S-38130	System safety engineering
MIL-HDBK-141	Optical design
FED-STD-595	Colors

APPENDIX B

GLOSSARY

AAAIS - Advanced Army Aircraft Instrumentation System - A contact analog, vertical situation display, head down, raster generated, for use in Army aircraft.

AAFSS - Advanced Aerial Fire Support System - A rigid rotor helicopter designed to provide fire support to ground troops and armed escort for helicopters. The avionics package will be patterned after the IHAS. (q.v.)

ACCOMMODATION - Adjustment of focus of eye for different distances, accomplished by thickening or flattening of the lens.

ACUITY-VISUAL - In general, the ability of the eye to see fine detail. At least five types are of interest in display design.

a. Minimum visible refers to the ability to see a point source of light. It is a function of intensity.

b. Minimum perceptible, also called spot detection, is the ability to see small objects against a plain background. Size, brightness, and contrast are determining factors.

c. Minimum separable, also called gap resolution, refers to the ability to see objects as separate when they are close together. This is similar to radar resolution.

d. Vernier is the ability to recognize that two lines drawn end to end are slightly offset from each other.

e. Stereoscopic is the primary binocular ability of the eyes to determine which of two objects is closer; also called depth perception.

ADAPTATION, DARK - A process whereby the eye attains greater sensitivity to light when exposed to an illumination lower than that to which it was previously exposed; it involves scotopic (rod) vision and chemical changes in the eye.

ADAPTATION, LIGHT - A process by which the eye attains less sensitivity to light when exposed to an illumination greater than that to which it was previously exposed; it involves photopic (cone) vision and chemical changes in the eye; generally the reverse of dark adaptation.

ADF - (Automatic Direction Finder) - A radio device composed of a radio receiver, sense and directional (loop) antennas, and a bearing indicator; it indicates bearing from an aircraft to a ground transmitter.

ADI - See ATTITUDE DIRECTOR INDICATOR and ANALOG DISPLAY INDICATOR.

ADL - (Armament Datum Line) - An edge view of a horizontal plane through an aircraft used as a reference for aligning weapons. The ADL is usually calculated on the basis of a combination of nominal (or optimal) values for airspeed, altitude, attitude, and gross weight.

AIDING - A technique used in control system design whereby derivatives of the actual controlled variable are combined by means of feedback loops in order to improve or facilitate control performance. See QUICKENING.

AIR VECTOR - See FLIGHT PATH.

AIRCRAFT STABILIZED - A display condition wherein the symbols are oriented with respect to the aircraft or display framework and are not affected by changes in the aircraft attitude. Sometimes called roll stabilized or display stabilized.

ANALOG DISPLAY INDICATOR - (ADI) - The direct view vertical situation display in the A-6A aircraft; the official designation is AN/AVA-1.

ANGLE OF ATTACK - The acute angle between the chord of an airfoil and a line representing the undisturbed relative airflow.

ANIP - Army-Navy Instrumentation Program; forerunner of JANAIR.

ANTIREFLECTANCE COATING - A thin film single or multilayer optical coating used to minimize reflected light from glass or other materials. (Sometimes called quarter wavelength or HEA coating.)

APEXER - (Approach Indexer) - An instrument which provides angle of attack information (relative to a desired value) for control of pitch attitude or airspeed during the final approach phase of landing, especially carrier landing.

ASPECT RATIO - The ratio of the frame (*i.e.*, picture) width to frame height in television. It is 4 to 3 in the United States and Great Britain for commerical television.

ATTITUDE DIRECTOR INDICATOR - (ADI) - An electromechanical device which displays aircraft attitude by means of a rotating sphere. Sometimes called artificial horizon, gyro horizon, or 8-ball.

B

BANK - Inclination of an aircraft such that the lateral axis makes an angle with the horizontal. See ROLL. Bank is not synonymous with turn or roll.

BREWSTER'S ANGLE - The angle of incidence for which a light wave polarized parallel to the plane of incidence is wholly transmitted, with no reflection.

BRIGHTNESS - The perceived intensity of light; the sensation as distinguished from the photometric quantity, luminance. See also LUMINANCE, LUMINOSITY, and ILLUMINANCE.

C

CALIBRATED AIRSPEED - Indicated airspeed rectified to compensate for instrument and installation errors. Calibrated airspeed is equal to true airspeed in a standard atmosphere at sea level.

CATEGORY I, II, and III LANDING CONDITIONS - These terms apply to Instrument Landing System (ILS) approach procedures as specified by the Federal Aviation Agency (FAA). Tentatively, these are:

<u>Category I</u> - provides for approaches to a decision height of not less than 200 feet and visibility of not less than 1/2 miles (200 - 1/2) or a runway visual range (RVR) of 2400 feet.

<u>Category II</u> - provides for approaches to a decision height of not less than 100 feet and 1200 feet RVR.

<u>Category III</u> - provides for approaches to 0 feet ceiling and visibility.

Note that these definitions are stated in an overly simplified form in keeping with the scope of glossary terms and the purposes of this report. The interested reader should obtain *Terminal Instrument Procedures (TERPS)* and other applicable publications from the FAA for more definitive and current data.

Pending changes to the above (which may be issued in November or December, 1967) may delete Category I altogether. Category II will probably be specified in terms of minimum decision height for certain classes of aircraft, and will probably vary for certain airports and according to available landing facilities (*e.g.*, ILS or precision approach radar, PAR). Details are not firm at this time.

CIRCULAR POLARIZER - Is a sandwich consisting of a piece of linear polarizer bonded to a quarter-wave retardation sheet oriented at an angle of 45° to the transmission direction of the polarizer.

CLUTTER - Interference, overlap, or obscuration of symbols on a display as a result of overcrowding or improper placement; an excess of information on a display which detracts from one's ability to process or interpret data; information on a display which is unnecessary or irrelevant to the user's immediate purpose.

COLLIMATED LENS SYSTEM - A lens system which renders diverging or converging rays parallel. It may be used to simulate a distant target or to align the optical axes of instruments.

COLLIMATION - The process of aligning the optical axis of an optical system to the reference mechanical axes or surfaces of an instrument; or the adjustment of two or more optical axes with respect to each other. The process of making light rays parallel.

COMBINER - (Combining Glass) - A singly ply or laminated glass mounted above the aircraft instrument panel used to reflect projected symbols to the pilot.

a. Curved - A curved combiner is a comparatively thick glass of either spherical or aspherical configuration.

b. Straight - A straight combiner is a thinner glass (compared to the curved) and provides a flat surface for reflection of projected symbols.

COMPASS COMPARATOR - A device which compares the heading indications of two compasses in an airplane (such as the pilot's and co-pilot's) and displays the amount and direction of difference.

COMPENSATORY TRACKING DISPLAY - See PURSUIT TRACKING DISPLAY.

CONES - The receptors for the optic nerve, located in the retina and concentrated in the fovea and macula, which are concerned with sharp vision, high ambient light, and color vision. See also RODS.

CONTACT ANALOG - A display wherein stylized symbols are used to create a partial visual analog of the real world as it would be if viewed through the windshield. The notion is that the display provides the pilot with an analog of contact or VFR flight.

CONTRAST - The degree of difference in luminance between light and dark figure/ground elements of an E/O display. The usual comparisons are of the range of gray scale tones available or of symbol to background luminances.

The recommended formula for specifying per cent display contrast is:

$$C = \frac{L_h - L_1}{L_1}$$

Where L_h = high luminance

L_1 = lower luminance

to express as a percentage multiply by 100.

COURSE - In air navigation, the planned route or direction of flight with reference to a line on the earth. Course refers to the intended path of flight over the earth whereas ground track refers to that made good.

CRAB ANGLE - The angular difference between the flight path and heading of an aircraft due to the effects of wind. Sometimes called drift angle.

CRITICAL FLICKER FREQUENCY - Alternate name for critical fusion frequency.

CRITICAL FUSION FREQUENCY - The rate of presentation of successive light stimuli which is necessary to produce complete fusion and to have the effect of continuous illumination.

D

DIPLOPIA - Any condition of the ocular mechanism in which a single external object is seen double.

DIRECT VIEW DISPLAY - A display that is viewed by looking directly at a surface or viewing medium which is opaque or apparently so; to be distinguished from projected displays of the look-through variety, such as head-up displays. Direct view displays are usually of the head-down type. See PROJECTED DISPLAY, HEAD-UP DISPLAY, and HEAD-DOWN DISPLAY.

DIRECT VIEW INDICATOR - (DVI) - The direct view VSD part of the V/HUD display group in the F-111B aircraft.

DISPLAY STABILIZED - See AIRCRAFT STABILIZED.

DRIFT ANGLE - See CRAB ANGLE.

E

EARTH STABILIZED - A display condition wherein the symbols are oriented with respect to an earth coordinate system and are therefore rotated or translated as a function of aircraft attitude.

ELECTROLUMINESCENCE - A light producing phenomenon caused by the application of an electric field to some phosphors; the direct conversion of electric energy into light within a phosphor.

E/O DISPLAYS - Electronic or optically generated avionics displays.

EXIT PUPIL - An image of the diaphragm, lens mounting, or similar obstacle which limits light ray transmission in an optical system (*i.e.*, an image of the aperture stop of an optical system or instrument).

EYE POSITION - An anthropometrically derived locus in the cockpit from which viewing angles are measured.

a. Erect - The eye position used for landing or when maximum over-the-nose vision is required.

b. Relaxed - The eye position used when over-the-nose vision is not required; *e.g.*, for en route flying.

F

FIELD OF VIEW (FOV) - Strictly speaking, the area or solid angle visible through an optical instrument. In E/O displays the term is used more generally to mean the area or solid angle subtended at the eye by the display. Note that this latter definition refers to the visual angle subtended by the display and not what the display represents in terms of real world coverage.

FLIGHT DIRECTOR - An electromechanical display device or instrument which combines an attitude indicator, magnetic heading indicator, ILS localizer, and glideslope indicator; it helps the pilot to visualize his attitude and movement with reference both to the horizon and to the ILS localizer course and glideslope.

FLIGHT DIRECTOR SYMBOL - See STEERING SYMBOL.

FLIGHT PATH - The path, track, or line connecting the continuous positions occupied by an aircraft moving through the air mass. Sometimes called air vector, or velocity vector. See also IMPACT POINT.

The above term means actual progression-made-good as distinguished from the desired pathway or "highway" used as a command indication on some contact analog displays.

FLIGHT PATH SYMBOL - In contact analog displays, the Flight Path Symbol is usually shown in perspective as a pathway, highway, or ribbon. The symbol shows the desired flight path of the aircraft and indicates own ship position in relation to that path. See PATHWAY, TRACKWAY, and FLIGHT PATH.

This term is easily confused with Flight Path. Pathway or Trackway are considered to be more desirable terms.

FLIGHT VECTOR - See VELOCITY VECTOR.

FLY-FROM - A scheme of command presentation in which a movable symbol is displaced from a null reference to indicate a deviation of status from desired performance. The response is to move (fly) the symbol away from its present position and back to the null position in order to correct the error. The opposite is fly-to.

FLY-TO - A scheme of displaying commands whereby the direction of displacement of a command symbol from its null reference corresponds to the direction in which the vehicle must be moved in order to correct the error. The response is to fly to the position of the movable symbol.

FOLDED OPTICAL SYSTEM - An off-axis optical projection system using front surfaced mirrors. This method is used to achieve a more compact layout of equipment than with an unfolded system, but it may entail a sacrifice of accuracy and/or resistance to vibration.

FOOT CANDLE (ft-c or c/ft^2) - A unit of illumination equal to that produced by a uniform point source of one standard candle on a surface, every point of which is one foot away from the source (equal to 1 lumen per square foot).

The foot-candle is a unit of measurement of the light incident to (falling on) a surface as distinguished from that emitted by or reflected from that surface. To convert from ft-L to ft-C, multiply by 0.3183 (*i.e.*, $\frac{1}{\pi}$).

FOOT LAMBERT (ft-L) - A unit of luminance or photometric brightness equal to the luminance of a perfectly diffusing, perfectly reflecting surface whose illuminance is one lumen per square foot (*i.e.*, 1 foot-candle). A foot lambert is a unit of emitted or reflected light as distinguished from that falling on a surface.

To convert from ft-C to ft-L, multiply ft-C by 3.142 (*i.e.*, π).

FRESNEL LENS SYSTEM - An apparatus used for carrier landing which provides visual indication of amount and direction of deviation of the aircraft from optimum glideslope.

FUSELAGE REFERENCE LINE - A line established on the fuselage of an airplane, usually within the plane of symmetry, used as a reference line when installing weapons, describing cockpit geometry, defining aircraft attitude, etc.

G

GAMMA (Γ) - A numerical indication of the degree of contrast in a television or photographic image.

GAMMA CORRECTION - In TV or photography, the correction of the effective value of gamma by introducing a non-linear output-input characteristic.

GLIDEPATH - An imaginary extention of the runway centerline which defines the required path of approach (on the earth plane). Not to be confused with glideslope. (q.v.)

GLIDESLOPE - An inclined plane, extending upward from the runway at a given angle, which defines the required altitude and rate of descent for landing.

Note that glideslope refers to an angle in a vertical plane; whereas glidepath refers to a line on a horizontal plane.

GO-AROUND - To abort a landing attempt and re-enter the traffic pattern.

GLARE - Any brightness within the field of vision of such character as to cause discomfort, annoyance, interference with vision, or eye fatigue.

a. Direct - Glare cause by a light source in the visual field.

b. Specular - Reflected concentrated light as distinguished from diffused light; caused by reflecting bright surfaces.

GROUND SPEED - The horizontal component of aircraft rate of motion relative to the earth's surface with wind effects accounted for.

GROUND TRACK - The actual path, or track, of the aircraft over the surface of the earth. Ground track, which refers to the actual path, is to be distinguished from course which refers to the desired or command path.

H

HALATION - An area of glow surrounding a bright spot on a fluorescent screen; caused by scattering of light by the phosphor or by multiple reflections at front and back surfaces of the glass faceplate.

HEAD-DOWN DISPLAY - A cockpit display mounted below the top of the instrument panel. Such displays are usually of the direct view type; however, projected displays may be similarly mounted. In some applications, *e.g.*, helicopters, a head-down display may also be a look through type. In this situation, a special term such as head-down "window display" might be appropriate.

HEAD-UP DISPLAY - A cockpit display mounted above the top of the instrument panel. Such displays are usually of the projected vertical situation type. Optical gunsights and some peripheral displays are in this category.

HEADING - The horizontal direction in which an aircraft is pointed, expressed an an angle between a reference line (such as true north) and a line extending in the forward direction along the longitudinal axis of the aircraft. (Heading is not synonymous with YAW, COURSE, or GROUND TRACK q.v.).

HI-CON EL TECHNIQUE - A term used to describe high contrast filtering techniques that permit the absorption of a high percentage of ambient light without greatly reducing emitted light of the EL display.

HORIZON, LOCAL - A horizontal reference line, parallel to the earth plane and passing through the aircraft center of gravity, used to measure pitch and roll attitude.

HORIZONTAL SITUATION DISPLAY (HSD) - As used in this report, a generic term for E/O displays which provide navigational, tactical, map, chart, PPI, nd similar information in a horizontal coordinate system, *i.e.*, as a projection upon an imaginary horizontal plane beneath the aircraft. Other generic terms, distinct from HSD, are MULTI-SENSOR DISPLAY and VERTICAL SITUATION DISPLAY (q.v.)

IEVD - See INTEGRATED ELECTRONIC VERTICAL DISPLAY.

IHAS (Integrated Helicopter Avionics System) - A joint Army/Navy sponsored avionics display system designed to perform the airborne functions of navigation, flight control, station keeping, terrain following, terrain avoidance, and monitoring equipment status.

ILAAS (Integrated Light Attack Avionics System) - An integrated avionics package, similar to IHAS, except it will be used by carrier and land based fixed wing light attack aircraft.

ILLUMINANCE - The luminous flux (*i.e.*, the time rate of the flow of light, which indicates source intensity) incident upon a surface. A typical unit is the footcandle, which equals the illumination falling on a surface 1 foot from a one-candlepower source (*i.e.*, 1 lumen per square foot).

IMPACT POINT - The projection of the VELOCITY VECTOR (q.v.) of the aircraft upon a vertical plane forward of the aircraft; a representation of the point on that plane where the aircraft will impact if the flight path and/or speed are not changed. As customarily used, the term is synonymous with VELOCITY VECTOR, FLIGHT VECTOR, and FLIGHT PATH. (q.v.)

INCIDENCE, ANGLE OF - The angle between an incident ray of light and a line normal to the reflecting or refracting surface; the angle between a line of sight and a line perpendicular to a surface.

INDICATED AIRSPEED (IAS) - The speed (pressure) of the relative wind approaching the aircraft, as measured by a pitot-static indicator.

INNER MARKER BEACON - A marker beacon located near the approach end of the runway in an instrument landing system. It indicates to the pilot, both aurally and visually, that he is directly over the beacon at an altitude of 100 feet on his final ILS approach.

INSIDE-OUT DISPLAY - A display format which presents attitude in an earth-stabilized frame of reference. That is, the artificial horizon rotates as a function of roll and translates as a function of pitch while the aircraft symbol remains fixed. The presentation is analogous to the view through the windshield of the aircraft. See OUTSIDE-IN DISPLAY.

INSTANTANEOUS FIELD OF VIEW - See FIELD OF VIEW.

INTEGRATED ELECTRONIC VERTICAL DISPLAY - A direct view VSD display concept developed by Norden for experimental purposes. Formerly known as UCAD, Universal Contact Analog Display.

INTERLACE - A scanning process in CRT raster generation in which the distance from center to center of successively scanned lines is two or more times the nominal line width, so that adjacent lines belong to different fields.

ITERATION RATE - Data update frequency; writing rate; message transmission rate.

JANAIR - Joint Army-Navy Aircraft Instrumentation Research.

K

KEYSTONE DISTORTION - A trapezoidal distortion created by producing an image on a surface not normal to the direction of the source.

KINALOG - A type of attitude display in which both the aircraft symbol and the artificial horizon move in such a way that they agree with the visual and kinesthetic sensations of the pilot.

KNOT - A unit of speed equal to 1 nautical mile per hour (1.15 statute miles per hour).

LEVEL-ON-TOP - A terrain avoidance or terrain following term used to describe a maneuver that results in a wings-level condition at clearance altitude. This method prevents overshoot, yields minimum radar silhouette over the obstacle, and allows for quick noseover on the reverse slope.

LOCAL HORIZON - See HORIZON, LOCAL.

LOW LIGHT LEVEL TV (LLLTV or L^3TV) - A television system that uses vidicon or orthicon cameras to scan twilight and starlight scenes.

LUMINANCE - The light energy emitted or reflected from a surface; the quantitative attribute of light that correlates with the sensation of brightness. Formerly called photometric brightness. Measured in lamberts, foot-lamberts, or millilamberts.

LUMINOSITY - The brightness producing capacity of light. It is not a function of the physical intensity of the light (*i.e.*, of luminance) but of that light under all the prevailing physical conditions (distance, grain of the light surface, translucence of the medium, etc.) It is measured as the ratio of photometric quantity (lumens) to radiometric quantity (watts), *i.e.*, lumens per watt.

LUMINOUS FLUX - Rate of flow of light energy. The usual unit of measure is the lumen.

M

MACH NUMBER - The ratio of flight speed to the speed of sound in the medium in which the object moves. (Mach 1 equals 741 mph at sea level, approximately 645 knots; at 30,000 ft. mach 1 equals 675 mph or 587 knots).

MARK II AVIONICS SYSTEM - An integrated avionics package designed for use in the F-111A and FB-111 aircraft.

MEATBALL - The projected image on a carrier landing mirror system which indicates glideslope deviation.

MICROMESH FILTER - Trade name for a honeycomb type directional display filter. The device is designed to block incident light striking the display at certain angles. It also acts as a neutral density filter.

MICROVISION - Bendix trade name for a high resolution radar system used to reproduce, on a cathode ray tube in the aircraft, a pattern generated by a series of transponders on the ground.

MIL - a. One thousandth of an inch (0.001 in.)

b. One thousandth of a radian (*i.e.*, a milliradian) (0.001 radian = 0.0573°)

MILLIMICRON - One thousandth of a micron, hence 10^{-9} meter.

MULTISENSOR DISPLAY (MSD) - As used in this report, a generic term for E/O displays which present data from a variety of on-board sensors. For example, a display on which radar, TV, or infrared may be presented selectively. Other generic terms, distinct from the MSD, are VERTICAL SITUATION DISPLAY and HORIZONTAL SITUATION DISPLAY (q.v.).

N

NULL POSITION - The position of a symbol on a command display when the actual flight characteristic does not deviate from the desired flight characteristic. For example, when an aircraft is exactly on proper glideslope, the glideslope deviation indicator will be at null position.

O

OMNI - A radio station which provides bearing and range information for air navigation. Also called VHF omni-range radio or VOR.

ORTHICON - A TV camera tube in which a beam of low velocity electrons scans a photoemissive mosaic that is capable of storing a pattern of electric charges.

OUTER MARKER BEACON - A marker beacon located four to seven miles from end of runway in an instrument landing system. It indicates to the pilot, both aurally and visually, that he can begin his final approach.

OUTSIDE-IN DISPLAY - A display format which presents attitude in an aircraft-stabilized frame of reference. That is, the artificial horizon remains fixed and the aircraft symbol moves to indicate roll and pitch attitude. The presentation is analogous to standing behind one's aircraft and watching it maneuver. See INSIDE-OUT.

P

PATHWAY - See FLIGHT PATH SYMBOL.

PERSISTENCE - A measure of the length of time that the screen of a cathode ray tube remains luminescent after exitation is removed.

PHASE ADVANCEMENT - The British term for QUICKENING (q.v.).

PI - Projection Indicator, the head-up display part of the V/HUD display group in the F-111B aircraft.

PITCH - A component of attitude; the angle between a horizontal reference plane and a line extending forward along the longitudinal axis of the aircraft.

POLE TRACK - A head-up, projected, vertical situation display format designed by the SAAB Aircraft Co. The symbology is dominated by vertical bars which provide qualitative (and indirectly quantitative) altitude information. The display is intended primarily for low altitude flight and landing.

PROJECTED DISPLAY - Generally, any visual presentation of output information, as on a CRT, that is generated at one locus and transmitted for viewing at another.

In E/O display usage, the projected display is often originated on a small CRT, collimated, and displayed on a combining glass so that images appear superimposed on the real world at infinity. Such displays are usually, but not necessarily, of the head-up, vertical situation types.

PURSUIT TRACKING DISPLAY - A display format wherein both the index of desired performance and the index of actual performance move against a fixed scale or coordinate system. An alternative is a compensatory tracking display, on which only one index of performance is free to move, and the other is fixed. With a pursuit tracking display the operator is presented with independent indications of the performance of the target and his own vehicle. With a compensatory tracking display the operator receives only an indication of the difference between the performance of the target and his own vehicle.

Q

QUICKENING - A technique of displaying system dynamics whereby various derivatives of the controlled variable are combined and the resultant displayed to the operator as a single quantity. Quickening is especially useful in controlling the predicted tendency or future state of systems with long lag characteristics. Aiding and quickening are analogous techniques; the former applies to control system design and the latter to displays.

R

RASTER - The closely spaced parallel electronic line pattern traced over the surface of a CRT; the line pattern seen on the screen of a television picture tube when no video signal is present.

REFRESH RATE - The rate at which display information is rewritten.

RELATIVE WIND - The air that strikes an aircraft by virtue of the relative velocity between the two. (Also called apparent wind.)

RESOLUTION - A measure of ability to delineate detail or distinguish between nearly equal values of a quantity.

a. Elements - The number of discrete elements or cells within a given display area.

b. Optical - The ability of a lens system to separate two points.

c. Photographic - The number of resolvable line pairs which are clearly defined as separate lines composing an image.

d. Radar - The ability of the radar system to distinguish targets that are in proximity to each other.

e. Spot Size - The diameter of the electron beam; used as the measure of resolution for line written, Lissajous, and caligraphic CRT displays.

f. TV Vertical - The number of active raster lines on a display from top to bottom.

g. TV Horizontal - The number of picture elements or dots on a horizontal raster line. This is a function of bandwidth and active scanning time.

RODS - The receptors for the optic nerve, located in the retina and concentrated on the periphery of the fovea, which are concerned with night vision or low ambient light. See also CONES.

ROLL - A component of aircraft attitude; a rotation of an aircraft about its longitudinal axis.

ROLL STABILIZED - See AIRCRAFT STABILIZED.

ROLL SUM STEERING - A quickening technique wherein heading error and command rate of turn, appropriately weighted, are summed algebraically; the resultant is displayed to the pilot as a command bank angle.

S

SIDESLIP - A downward slip along the lateral axis of an airplane when its wings are sharply banked.

SMOOTHING - A technique for minimizing short term variations of data output of a system by averaging over time, thereby achieving a continuous dynamic effect even though the data are subject to oscillatory or step-like changes.

STANDARD TURN RATES (JET) -

a. For jet aircraft, a 1.5°/sec. rate of turn (4 minute turn). Sometimes called a Rate 1 turn.

b. For light aircraft or jets flying below 220 knots, a 3°/sec. turn (2 minute turn). Sometimes called a Rate 2 turn.

STROBING - An illusory effect occurring in television systems in which moving objects appear to change speed, stop, or reverse direction of motion.

T

TACAN (Tactical Air Navigation) - An air navigation system in which a single uhf transmitter, when interrogated by a transmitter in the aircraft, sends out signals that activate airborne equipment to provide range and bearing incidations with respect to the transmitter location.

TERRAIN -

a. CLEARANCE - A flight maneuver wherein a selected safe altitude is maintained to clear the highest terrain elevation at some range ahead of the aircraft.

b. FOLLOWING - A low-altitude high-speed flight technique whereby the aircraft hugs the terrain contours along the line of flight without making heading changes to maneuver around terrain obstacles.

c. AVOIDANCE - A technique similar to terrain following except that the aircraft also maneuvers laterally to fly around obstacles and through valleys; sometimes called valley following.

TO/FROM INDICATOR - A display device used in aircraft to show whether the numerical reading of an omnirange selector represents a bearing toward or away from an omni-directional station.

TRACKING, COMPENSATORY - Intermittent or continuous adjustment of an instrument or machine to maintain a normal or desired value.

TRACKING, PURSUIT - Intermittent or continuous adjustment of an instrument or machine to follow a moving target.

TRACKWAY - Alternate term for Pathway.

TRICHROIC - A color separation thin film filter deposited on HUD combiners to reflect (*i.e.*, block) a narrow band of light wavelengths while transmitting the energy at other wavelengths. The filtered wavelengths are selected to match the color of the HUD image, thereby obtaining a contrast enhancement effect for the display.

TRUE AIRSPEED - The actual speed of an aircraft relative to the air mass, *i.e.*, the calibrated airspeed corrected for air temperature and density.

U

UCAD - See INTEGRATED ELECTRONIC VERTICAL DISPLAY.

V

V/HUD - Vertical /Head-up Display, the name for the vertical situation display group in the F-111B aircraft.

VELOCITY VECTOR - The direction of flight or vector of the aircraft through the air mass. It is a function of both aircraft speed and attitude. As customarily used, the term is synonymous with Impact Point, Flight Vector, Flight Path. See FLIGHT PATH and IMPACT POINT.

VERTICAL SITUATION DISPLAY (VSD) - As used in this report, a generic term for E/O displays which present aircraft attitude and command information as a projection upon an imaginary vertical plane forward of the aircraft. Other generic terms, distinct from VSD, are MULTISENSOR DISPLAY and HORIZONTAL SITUATION DISPLAY (q.v.)

VERTIGO - A sensation of whirling, dizziness, or giddiness, sometimes accompanied by nausea, attributed to overstimulation of the semicircular canal otolith function and disorientation.

VHF OMNIRANGE - See OMNI.

VIDICON - A TV camera tube in which a charge-density pattern is formed by photoconduction and stored on a photoconductive surface that is scanned by an electron beam.

VIEWING ANGLE - The angle subtended by the line of sight and the viewed plane.

VISUAL ACUITY - See ACUITY, VISUAL.

VISUAL ANGLE - The angle subtended by an object in the visual field at the nodal point of the eye. This angle determines the size of the image on the retina.

VOR (VHF OMNIRANGE) - An omnirange operating in the band from 112 to 118 mc to provide bearing information for aircraft.

VORTAC - An air navigation system that combines VHF omnirange and Tacan equipment.

W

WATERLINE - An edge view of a horizontal plane through an aircraft. The base line of the aircraft is taken as waterline zero. The planes of all waterlines are parallel to the horizontal base line. Also called the fuselage reference line.

WAVEOFF - In carrier landing the act of refusing a landing to an approaching aircraft. It implies that an authority other than the pilot (*e.g.*, LSO, control tower, Data Link or an on-board computer) is ordering a go-around. See GO-AROUND.

WING CHORD LINE - An imaginary line through the airfoil parallel to the free airstream at zero lift and passing through the trailing edge. (Lift varies directly with the angle of attack of the aerodynamic chord). Also called Chordline, Airfoil Chord, and Aerodynamic Chord.

YAW - The rotational movement or oscillation of an aircraft about its vertical axis.

X
Y
Z

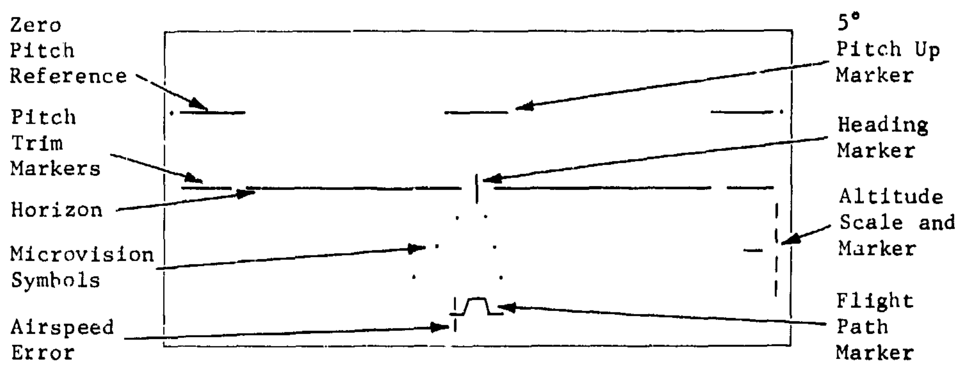
APPENDIX C

OTHER DISPLAY SYSTEMS

This appendix contains illustrations and brief descriptions of other recent vertical situation display designs which were not included in the analysis in Chapter III because there was insufficient information available to us about the details of these devices and their intended use. We present them here in order to round out the picture of the present state of VSD development. Accompanying each illustration is an identification of the symbols, a description of important system features, and the name of the manufacturer. The displays included in this appendix are:

- Bendix Microvision
- Kaiser FP-50
- Rank Cintel PEEP
- SAAB Pole Track
- Spectocom HUD
- Sperry HUD

BENDIX MICROVISION



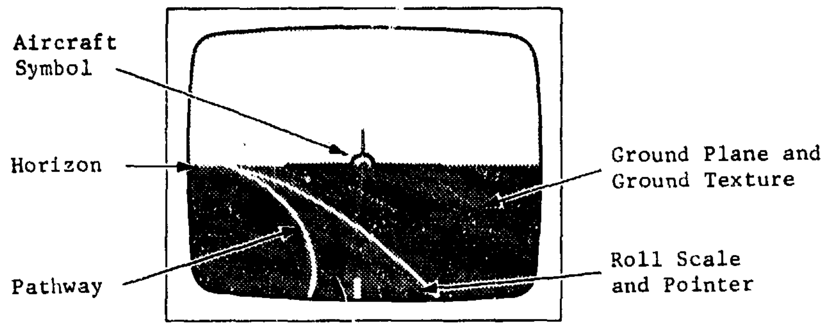
TYPE: VSD, projected, line-written

FEATURES:

- Display unit is binocular device which presents collimated image 20° vertically x 40° horizontally (binocular)
- Scaling 1:1
- Boom-mounted unit swings out of way when not in use or if abnormal G force develops
- Microvision system displays location of transponders along runway edge
- En route, terrain avoidance, and weapon delivery modes also available
- System can be adapted to display raster video

MANUFACTURER: The Bendix Corporation
Eclipse-Pioneer Division
Teterboro, New Jersey

KAISER FP-50



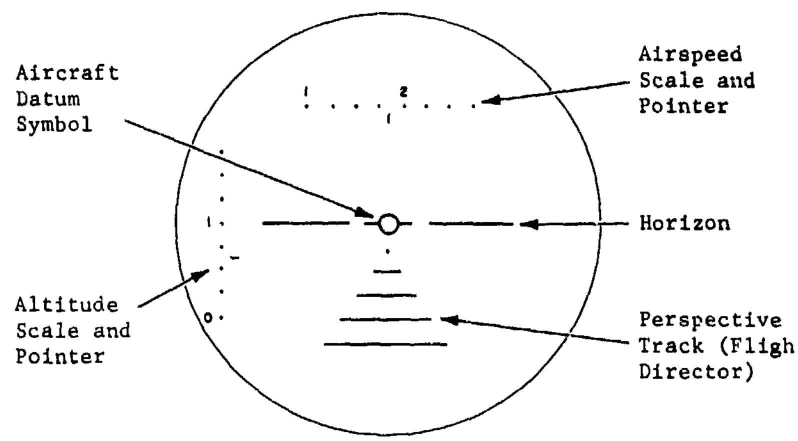
TYPE: VSD, direct view, raster

FEATURES:

- Display size 4-1/4 x 3-1/4 inches
- Seven shades of gray available
- Pitch trim control provides ±5° of adjustment
- Flight path commands can be generated by compass, VOR/OMNI, ILS, or ADF
- Compact size makes it suitable for installation in light aircraft

MANUFACTURER: Kaiser Aerospace and Electronics
1681 Page Mill Road
Palo Alto, California

PILOT'S ELECTRONIC EYELEVEL PRESENTATION (PEEP)



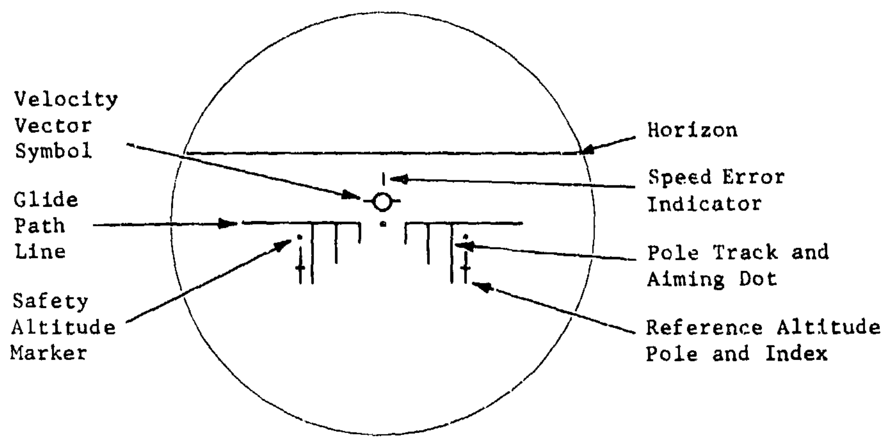
TYPE: VSD, projected, line-written

FEATURES:

- Gunsight type optical system, with collimating lens and flat-plate combiner
- Scaling 1:1
- Field of view not specified
- Flight director symbol can be driven by compass, navigation computer, VOR-OMNI, or ILS
- Manual brightness adjustment

MANUFACTURER: Rank Cintel Limited
Worsley Bridge Road
Lower Sydenham, London S.E. 26

SAAB POLE TRACK



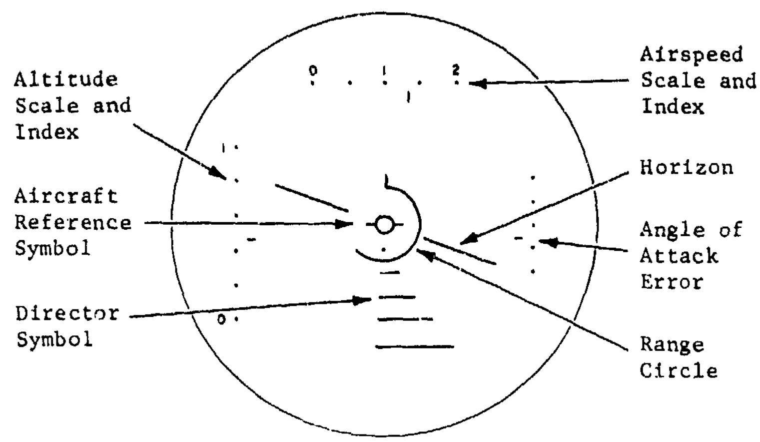
TYPE: VSD, projected line written

FEATURES:

- Gunsight type optical system, with collimating lens and flat-plate combiner
- Field of view 20° x 20° (monocular)
- Same symbols used for en route, terrain avoidance, or landing
- All information, except speed error, presented in same coordinate system
- No scales or numerals used
- Angular dimensions of pole track chosen to permit small and precise corrections

MANUFACTURER: Svenska Aeroplan Aktiebalaget (SAAB)
Linkoping, Sweden

SPECTOCOM HUD



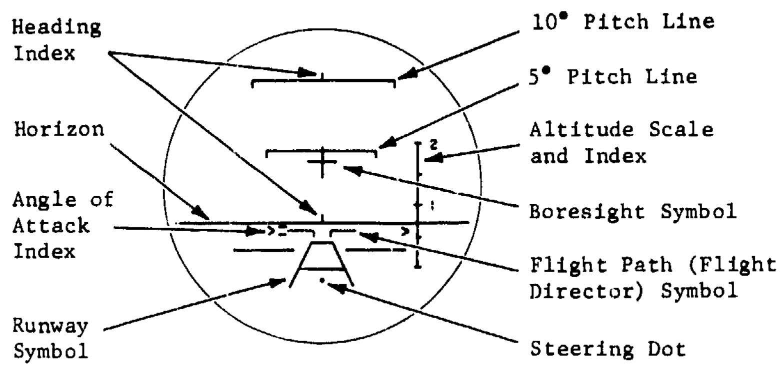
TYPE: VSD, projected, line written

FEATURES:

- Gunsight type optical system, with collimating lens and flat-plate combiner
- Field of view 14° x 14° (monocular)
- Only horizon is earth stabilized; all other elements are display stabilized
- Same symbols used for takeoff, en route, and landing

MANUFACTURER: Specto Limited of Great Britain
Imported by Computing Devices of Canada
Ottawa, Canada

SPERRY HUD



TYPE: VSD, projected, line written

FEATURES:

- Gunsight type optical system, with collimating lens and flat-plate combiner
- Field of view: 11° x 11° (monocular)
- Scaling 1:1
- Display also has takeoff, en route, and terrain following modes (See p.107 for illustration of terrain following symbology.)

MANUFACTURER: Sperry Gyroscope Company
Great Neck, L.I., New York

APPENDIX D

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APPENDIX E

REFERENCES

The following is a listing by chapter and section of the source materials cited in this report. Only the short form of citation is given here; full identification of the documents is contained in the bibliography (Appendix D). Principal sources are denoted by an asterisk (*).

CHAPTER I - INTRODUCTION

None

CHAPTER II - DISPLAY CATEGORIES

DEFINITIONS

Carel (1965)

DIRECT VIEW VERTICAL SITUATION DISPLAYS

Carel (1965)

PROJECTED VERTICAL SITUATION DISPLAYS

Campbell (1955)

Roscoe (1952)

HORIZONTAL SITUATION DISPLAYS

Carel (1965)

Honigfeld (1964)

JANAIR (1966)

Roscoe (1967)

CHAPTER III - INFORMATION REQUIREMENTS

INTRODUCTION

Carel (1965)

AIRCRAFT TYPE AND MISSION

None

CONTEMPORARY E/O DISPLAYS

None

INFORMATION REQUIREMENTS STUDIES

Baxter (1963)

Baxter and Workman (1962)

Behan *et al.* (1965)

Carel (1965)

Douglas Aircraft Co. (1962)

Grumman Aircraft Engineering Corp. (1964)

Johnson and Momiyama (1964)

Morrall (1966)

Naish (1965)

Semple and Schwartz (1966)

Soliday and Milligan (1967)

Sperry Gyroscope Co. (1963)

Williams and Kronhold (1965)

ANALYSIS OF CONTEMPORARY VERTICAL SITUATION DISPLAYS[1]

F-111

General Dynamics Fort Worth (1966)

Grumman Aircraft Engineering Corp. (1964)

Grumman Aircraft Engineering Corp. (1965)

A-6

Manufacturer's unpublished materials and personal interviews with designers

[1] *Documents in this section are not cited in the report. They are included here as reference documents for each of the displays analyzed.*

ANALYSIS OF CONTEMPORARY VERTICAL SITUATION DISPLAYS (Cont.)[1]

A-7

Manufacturer's unpublished materials and personal interviews with designers

ILAAS

Naval Air Systems Command (1966)

AAAIS

University of Pittsburgh (1965)

Douglas Aircraft (1966)

IHAS

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ANALYSIS OF CONTEMPORARY HORIZONTAL SITUATION DISPLAYS[1]

Hughes TID

Grumman Aircraft Engineering Corp. (1964)

ITT Gilfillan Mk II and CDC Moving Map

JANAIR (1966)

AAAIS

University of Pittsburgh (1965)

[1] *Documents in this section are not cited in the report. They are included here as reference documents for each of the displays analyzed.*

CHAPTER III - INFORMATION REQUIREMENTS (Cont.)

SYNTHESIS OF INFORMATION REQUIREMENTS FROM STUDIES AND DISPLAYS

None

TERRAIN AVOIDANCE

Lambert (1964)

McGrath *et al.* (1964)

Naish (1961)

Nordstrom (1965)

Soliday and Milligan (1967)

WEAPON DELIVERY

None

<u>CHAPTER IV - SYMBOLOGY</u>

INTRODUCTION

Honigfeld (1964)

Roscoe (1967)

Walchli (1967)

CODING THEORY AND PRINCIPLES

Alluisi *et al.* (1957)

*Baker and Grether (1954)

Crumley *et al.* (1961)

*Foster (1964)

Garner (1962)

Gebhard (1949)

*Honigfeld (1964)

Miller (1956)

*Muller *et al.* (1955)

Naish (1967)

*Sampson and Wade (1961)

Shannon and Weaver (1949)

CODING DIMENSIONS

Air Standardization Coordinating Committee (1964)

*Baker and Grether (1954)

Botha and Shurtleff (1963b)

*Bowen *et al.* (1959)

Brooks (1965)

Casperson (1950)

Cohen and Webb (1953)

Conover and Kraft (1958)

*Cornog and Rose (1967)

Dardano and Stephens (1958)

Elias (1965)

Elias *et al.* (1964)

Foster (1964)

Gebhard (1948)

Gerathewohl (1953)

Gerathewohl and Rubinstein (1953)

Halsey (1962)

Halsey and Chapanis (1953)

Harris *et al.* (1956)

Hitt (1961)

*Honigfeld (1964)

McLean (1965)

Moore and Nida (1958)

Morgan *et al.* (1963)

*Muller *et al.* (1955)

Newman and Davis (1961)

Pizzicara (1966)

*Poole (1966)

Reese *et al.* (1953)

*Rizy (1965)

Rowland and Cornog (1958)

*Sampson and Wade (1961)

Seibert (1964)

Seibert *et al.* (1959)

*Shurtleff (1967)

Shurtleff and Owen (1966)

Shurtleff *et al.* (1966a)

Shurtleff *et al.* (1966b)

Sleight (1952)

Smith (1962)

Smith (1963)

Smith *et al.* (1965a)

CODING DIMENSIONS (Cont.)

JANAIR (1966)

Kelly (1960)

Kuehn (1966)

Smith *et al.* (1965b)

Snadowsky *et al.* (1964)

Steedman and Baker (1960)

REFERENCE SYSTEM AND DISPLAY DYNAMICS

*Baker and Grether (1954)

Bauerschmidt and Roscoe (1960)

Behan *et al.* (1965)

Browne (1945)

Campbell *et al.* (1955)

*Carel (1965)

Christiensen (1955)

Duerfeldt (1956)

Emery and Koch (1965)

Fitts and Jones (1947)

Fitts *et al.* (1949)

*Fogel (1963)

Gardner (1950)

Gardner and Lacey (1954)

JANAIR (1966)

Lambert (1964)

Loucks (1945)

Loucks (1949a)

Loucks (1949b)

McCormick (1964)

Morgan *et al.* (1963)

Naish (1961)

Naish (1962)

Naish (1964)

Naish (1965)

Payne (1952)

Roscoe *et al.* (1952)

Roscoe (1954)

*Roscoe (1967)

Sampson and Wade (1961)

*Williams *et al.* (1956)

*Wulfeck *et al.* (1958)

CHAPTER IV - SYMBOLOGY (Cont.)

FORMAT AND PLACEMENT

Austin *et al.* (1967)

Bruner *et al.* (1956)

Carel (1965)

Foster (1964)

Poole (1966)

Poole and Koppel (1965)

Whitham (1965)

TOWARD A COMMON LANGUAGE

Baker and Grether (1954)

Brown (1959)

Heininger (1966)

Hill and Chernikoff (1965)

Kelso (1964)

McCormick (1964)

Morgan *et al.* (1963)

Williams *et al.* (1956)

Williams *et al.* (1965)

Wulfeck *et al.* (1958)

CHAPTER V - DISPLAY CHARACTERISTICS

INTRODUCTION

None

VISUAL FACTORS

Buddenhagen and Wolpin (1961)

Chalmers *et al.* (1950)

Duntley *et al.* (1964)

Glover (1955)

*Kelley *et al.* (1965)

Kelso (1965)

Pitts (1963)

Rock (1953)

Sears (1958)

*Smith and Goddard (1967)

Spragg and Rock (1948)

U.S. Navy Hydrographic Office (1963)

VISUAL FACTORS (Cont.)

Ketchel (1967)

Luxenberg and Bonness (1965)

*Morgan *et al.* (1963)

Whiteside (1965)

*Wulfeck *et al.* (1958)

LUMINANCE AND CONTRAST

Alluisi *et al.* (1957)

*Blackwell (1946)

*Carel (1965)

*Claver (1966)

Crouch (1958)

General Electric Co. (1961)

*Hanes and Williams (1948)

Hardy (1963)

Hoffman *et al.* (1967)

*Kelley *et al.* (1965)

*Ketchel (1967)

Kilpatrick (1966)

Lally (1966)

Luxenberg and Bonness (1965)

McCormick (1964)

Miller (1966)

*Peterson (1966)

*Pfahnl (1961)

Slocum *et al.* (1967)

*Stevens (1962)

FLICKER

*Carel (1965)

Crozier and Wolf (1941)

*Graham *et al.* (1965)

Grob (1964)

Lloyd (1962)

*Morgan (1965)

Poole (1966)

Schade (1948)

Turnage (1966)

Underwood (1966)

FILTERS

Carel (1965)

Hanes and Williams (1948)

Hubner and Blose (1966)

Justice and Liebold (1965)

Kelley *et al.* (1965)

Ketchel (1967)

Lally (1966)

Peterson (1966)

Pfahnl (1961)

Pizzicara (1966)

Polaroid Corp. (1967)

RESOLUTION

Beste (1963)

*Carel (1965)

Clauer (1966)

*Fink (1952)

Harsh (1966)

Peterson (1966)

Poole (1966)

Shurtleff *et al.* (1966)

*Shurtleff (1967)

Slocum *et al.* (1967)

*Whitham (1965)

Wurtz (1967)

COLOR

Damon (1966)

French (1967)

*Pizzicara (1966)

OPTICS AND FIELD OF VIEW

None

STANDARDS OF MEASUREMENT

None

CHAPTER V - DISPLAY CHARACTERISTICS (Cont.)

UNDESIRABLE QUALITIES

None

SUMMARY OF DISPLAY CHARACTERISTICS

None

CHAPTER VI - SUMMARY AND RECOMMENDATIONS

None